AVIATION

From the Ground Up

MANLY

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AVIATION

From the Ground Up

A PRACTICAL INSTRUCTION AND REFERENCE WORK ON AVIATION AND ALLIED SUBJECTS

Including

Theory of Flight, Details of Airplane Construction, Airplane Engines, Rigging, Instruments, Weather Forecasting, Aërial Navigation, Stunts, How to Learn Flying, Parachutes, Air Commerce Regulations and a Dictionary of Aviation Words and Terms

Written in Plain Understandable English

BY

LIEUT. G. B. MANLY

U. S. ARMY AIR SERVICE, RES.

ILLLUSTRATED

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PREFACE

AVIATION FROM THE GROUND UP has been written, not for the technician, the aëronautical engineer or the seeker after technical detail, but for the average everyday man who wants to learn the practical side of aviation. The writer has flown before, during the World War and since and appreciates that simplicity in explanation is desired by the layman interested in aëronautics. In this book I shall try to pass along to you the information which I fervently wished might have been given to me when I first took up my training.

Recent accomplishments by aircraft have created for this fascinating pursuit a world-wide interest which has induced powerful organizations to become intimately associated with it. Among them are found Henry Ford, the Du Ponts, the General Motors Corporation, Fokker and the Junkers. The latter two are primarily foreign manufacturers who have moved to or have established factories in this country.

The airplane has been found the best medium of transportation for explorers and surveyors in their investigation of country heretofore inaccessible to man. Air mail is being carried today by private companies on a sound commercial basis. Passenger and express air lines are in operation all over the world, running on schedules which compare favorably with railroad transportation. Planes are being manufactured on a mass production basis instead of on special order and are being designated by model number, as is the case with automobile manufacture. New manufacturers are entering the business all the time, both in the field of complete airplanes and in the production of parts expressly for aviation purposes.

The airplane has become about as foolproof as the average automobile in mechanical features. It may be flown and maintained with no great amount of technical knowledge. But just as a person

makes a better automobile driver when he is acquainted with what goes on under the floor boards, so he makes a better air pilot or mechanic when he is acquainted with what goes on under, and over, the airplane wings. There is no great mystery connected with airplane flight; it follows certain basic principles, or laws, and it is the purpose of this book to explain these things in a very elementary way, paving the way for deeper study later on for those who desire it.

THE AUTHOR

CONTENTS

AVIATION

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CHAPTER I

HISTORY OF FLIGHT

EVER since the world began boys have had an overwhelming desire to do things they are not supposed to do. And what are men, but grown-up boys? That desire to do things we are not supposed to do has been the prime mover behind some of the greatest inventions. Man was created to walk at a certain rate of speed on dry land. Water offered a great temptation, and seeing fish moving so comfortably about in it, prompted man to explore the possibilities. As a result, man swims. He cannot swim for great distances so he invented first the oar-propelled boat. Then more speed was desired and the sailboat came into being, and the desire for still more speed created the steam boat.

Still, this entering the fishes' element was not accomplished to man's entire satisfaction until the invention of the submarine; then he was able to dive down to the depths of the ocean and see just what was so interesting to all the fish.

The flight of birds has always mystified and challenged man—something he was not supposed to do. Yes, but does a young boy want to play baseball on a school day? He does! So man set about finding out what he could about flying.

As far back as the thirteenth century men were thinking about it. Roger Bacon then prophesied that "one day an instrument may be made to fly withal if one sit in the midst of the instrument and doo turne an engine by which the wings, being artificially composed, may beate the ayre after the manner of a flying bird."

Ancient history contains the record of a man named Danti who at one time made a brave attempt to fly at Perugia. He had constructed a winged contrivance that made a "horrible hissing sound." History says nothing about the motive power.

Leonardo da Vinci was the first real pioneer in the science of flight. He worked with theory, which is usually the forerunner of practice, and he believed that bird flight was governed by certain basic mathematical laws. He also contended that it was entirely possible for humans to imitate bird flight provided air, the medium in which such flight took place, was first studied and understood. This man is also given credit for the invention of the parachute which has become the aërial life-saver of today.

Borelli came next in line of aërial pioneers. His study and experiments convinced him that man's strength, considering his weight, made it impossible for him to fly by his unaided physical efforts. Borelli's work resulted in turning attention to "lighter-than-air" flight in preference to "heavier-than-air" machines.

This resulted in some paper-bag manufacturers by the name of Montgolfier experimenting with balloons. They had often found amusement in filling inverted paper bags with steam, smoke and finally with hot air and watching them float up in the air. Hot air was found to work best, but the bags always turned over, let the hot air out, and fell back to the ground before they reached any considerable height. Then strings were attached to the lower edges of the bag and a weight fastened to them. This overcame the upsetting problem and experiments went ahead.

To this day the balloonists' coat-of-arms consists of the figures of a sheep, a duck and a rooster. This is because those creatures were the first living things sent aloft to any great altitude to find out if life could exist far above the earth. When these real pioneers came back to earth living and showing no ill effects from their experience, a man-carrying balloon was constructed and, in 1780, a Frenchman by the name of Rozier made the first balloon ascension by a human being.

Balloons were greatly improved from that time on, finally being propelled by power and steered. This led eventually to the development of our modern dirigible airship.

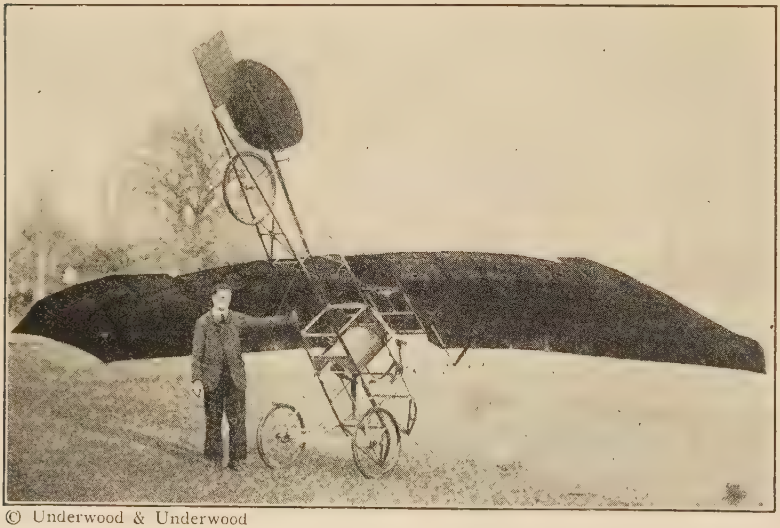
The interest in balloons and their possibilities somewhat retarded

development of heavier-than-air machines, although in 1796 a working model of the "helicopter" was designed. This was the first machine to use camber in the wings and a tail surface for control. A helicopter is a machine designed to rise straight up from the ground rather than to require running over the ground in order to attain flying speed. This type of machine was invented by Sir George Cayley, affectionately referred to as "The Father of British Aëronautics." He also investigated the possibilities of using steam power for airplanes and dirigibles.

Otto Lilienthal in one of his Gliders.

One of the best known of the very early pioneers was Otto Lilienthal, a Dutchman, who contributed valuable data from glider experiments between 1871 and 1895. In the latter year he met death in the crash of one of his gliders. He experimented with gliders altogether in order to test the action of different wing shapes and control surfaces. He was aware of the advantage of camber in the wings and used it in all his gliders. He also controlled the

machine in the air by shifting the weight of his body from one place to another and was the first to use this principle of control.



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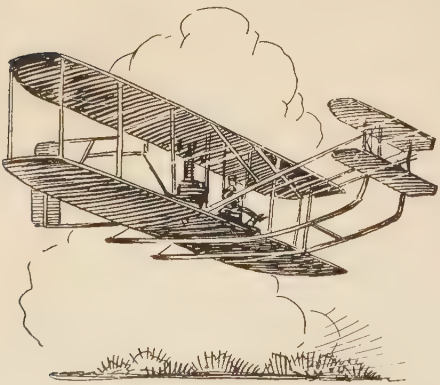
Another old-style Glider.



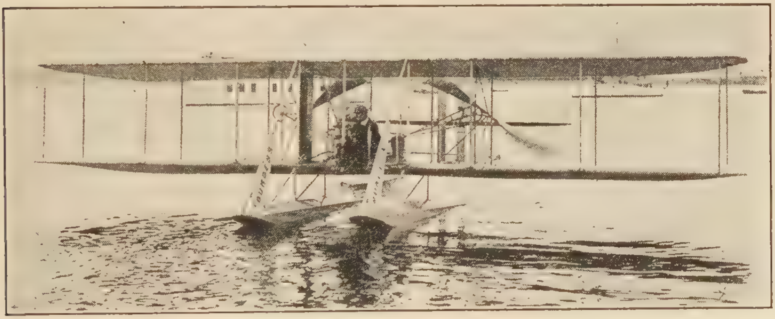
A 1904 Wright Biplane, pusher type, with elevators in front.

Sir Hiram Maxim, working at the same time as Lilienthal, conducted his experiments with a view of supplying engine power to his machines, and finally built a machine which, even if it did not really do so, showed that it could be made to carry a power plant and lift itself by its own power.

Since 1895 the great advance in Aëronautics can be credited to the efforts of Prof. Samuel P. Langley and to the Wright brothers, Orville and Wilbur.

Early in 1928 an argument arose as to which was the first to construct and successfully fly a heavier-than-air machine that flew by its own power and carried a man. Some claim that Langley did and just as many claim that the Wrights did. Anyway, only one or two men have been found who claim to have actually seen Langley's "airdrome," as he called it, in the air carrying a man. His practical experiments were carried out in great secrecy until he considered the machine sufficiently perfected to give a public demonstration. Langley at this time was head of the Smithsonian Institution, and experimented with the effect of moving air upon plane surfaces until he proved absolutely the practicality of heavier-than-air, power-driven airplane flight.

A working model that Professor Langley built was flown with success in 1903, but his first full size machine was wrecked in attempting to take off in its first public demonstration. Langley died soon after and many attribute his death to a broken heart over the failure of his life's work to perform satisfactorily.



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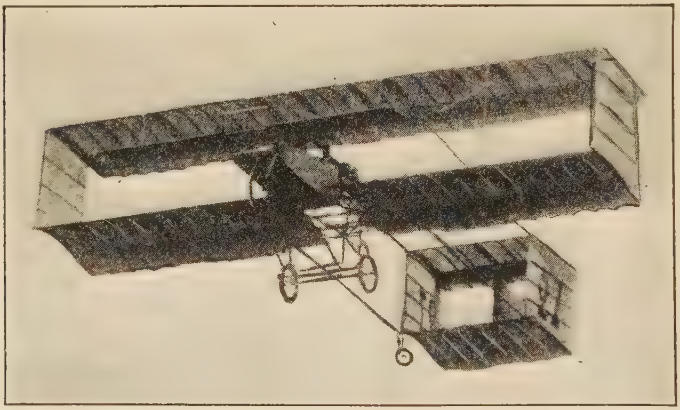
An early Wright Hydroplane.

During this time the Wright brothers, engineers and bicycle manufacturers, were busy with their machine and are given credit for making and successfully flying the first man-carrying, engine-driven airplane. They experimented intensively with gliders during 1901 and 1902 at Dayton, Ohio, then moved to Kitty Hawk, North Carolina. Unable to find an automobile manufacturer with sufficient courage to undertake construction of a power plant for their needs, they finally made their own. Propellers proved a problem,

but they finally overcame this obstacle and with the help of Chanute, another experimenter, completed their machine. Then, after several delays and postponements, the first accredited sustained flight of a man-carrying, engine-driven, heavier-than-air machine was made with Orville Wright at the controls on the morning of December 17, 1903.

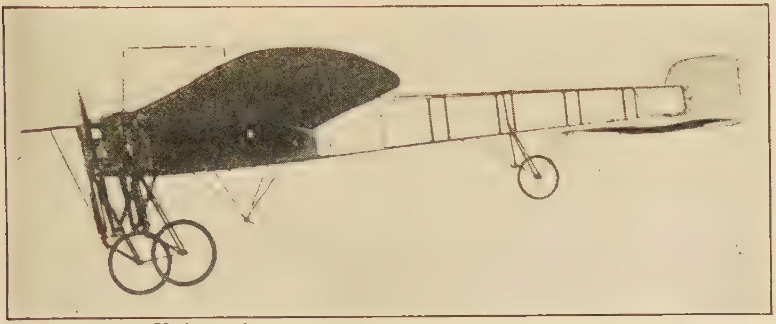
It was not until nearly a year later, September 15, 1904, that Orville Wright was successful in making the first turn in the air, the previous flights having been straight ahead with no directional control. On September 24 of the same year he made the first circle, and on October 4 the Wrights succeeded in keeping their machine in the air for over thirty minutes. The year 1908 saw the first real public flight of the Wright brothers.



An old Voisan resembling a box-kite.

A man by the name of Glenn Curtiss, a name later to become famous in aviation, entered the field not long afterwards and was the first to give a pre-announced public exhibition flight. This took place on July 4, 1908, and he won the *Scientific American* trophy by flying three-fifths of a mile with a machine driven by an eight-cylinder, air-cooled engine having the propeller attached directly to the engine crankshaft. Heretofore propellers had been driven by the engine through a chain and sprocket arrangement.

In 1910 the world was set aflame—nearly as great excitement prevailed as when Lindbergh accomplished his great flight. The news was flashed by cable that Bleriot, a Frenchman, had successfully flown across the English Channel in a monoplane!



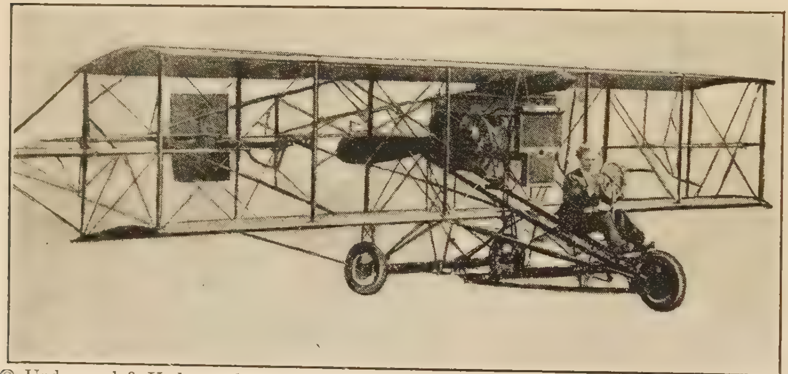
One of the first Monoplanes.

Two intrepid American flyers, named Rogers and Fowler, then attempted a flight across the United States. This, however, turned out to be more of a tour than a great flight. The machine had to be completely rebuilt before it reached its destination and the event proved to be somewhat of an endurance contest between the plane and the pilots.

A wonderful aërial performance was staged by Art Hoxie in 1912 when he flew from Chicago to St. Louis without stopping. An air race between New York City and Chicago convinced the public that something was in the air. These trips are made now by regular passenger and mail planes flying daytime, night time, winter and summer, rain or snow.

The World War no doubt advanced aviation far beyond the stage it would have reached today under normal conditions. The "race for supremacy of the air" by the warring nations resulted in aviation developing by leaps and bounds. The airplane using a propeller placed at the rear end of the engine and called a "pusher" was replaced by the plane with the propeller in front, pulling the machine through the air and called a "tractor." Engines were developed and improved to have an output of from 150 horsepower for light

machines to 850 horsepower for large bombing planes. Today's engines develop even greater horsepower. Quite a contrast between them and the fifty to eighty horsepower engines of 1912.



A 1911 model, pusher Biplane.

Rapid development and rejection in constructional design took place during this period. Planes with single wings, double wings, triple wings and even quadruple wings came and went quickly. The accepted design finally settled down to the double-wing type, or biplane as it is called, although single-winged monoplanes were becoming more and more popular toward the end of the war. The latter design is receiving the greatest amount of attention today, due possibly to the success this type has had in making historic flights.

Patriotism and the rich rewards offered by the various governments at war naturally attracted some of the best engineering brains in the world. Unlimited resources and experimental laboratories supplied these brains with the necessary tools. Some of these very highly trained men were retained after the war, both by the nations and by private manufacturers, and to these men is due the more recent developments and improvements in aviation. They have built the machines and trained the personnel that have made possible the epochal flights which include Byrd's flight to the North Pole; the eastward transatlantic flight by way of the Azores and Spain; the U. S. Army's around-the-world flight in 1924; the flight of Lind-

bergh to Paris, of Chamberlain to Germany, of Gobel to Hawaii, and of Byrd to the coast of France, all during 1927. The year 1928 saw the flight westward of the giant Graf Zeppelin from Germany to America.

Reliability of the airplane was further demonstrated in 1929 by the sustained flight of the U. S. Army tri-motored plane *Question Mark* that stayed in the air for one hundred and fifty hours of continuous flight. This record stood for only a short time—until two amateur pilots took a single-motored ship aloft and didn't come down for seven days—one hundred seventy-two hours and thirty-one minutes, to be exact. Fuel and food were transferred from another plane during these flights and the single-motored ship was good for several hours more, but the propeller broke, due to striking the belt-buckle on the mechanic's suit while he was oiling the engine rocker arms.

Today there is a pathway of lights stretching across the continent and from Canada to Mexico to guide the night flyers. More than 1,000 powerful beacons light the heavens along the airways, while in between them at three-mile intervals are thousands of smaller lights. The landing fields are lighted so that it is as easy to land and take off at midnight as at midday. The same is true of all the leading countries of the world.

CHAPTER II

AIRPLANE PARTS AND TYPES

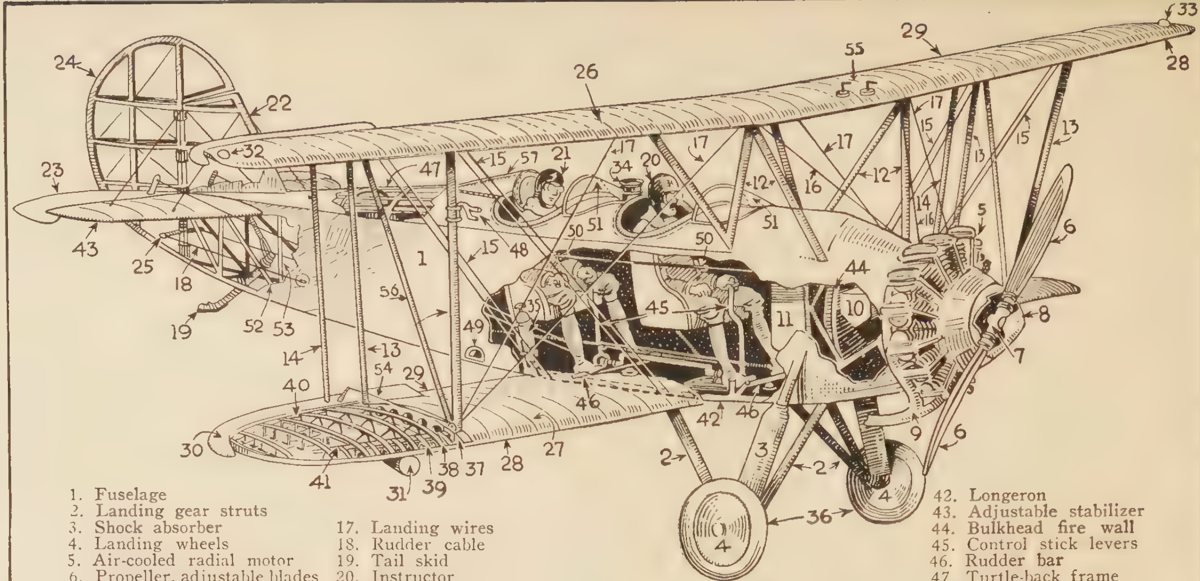
LET US first familiarize ourselves with the names of the parts that go to make up an airplane.

Wings.—One of the main parts is the wings. "Bi" means "two," therefore "biplane" means a two-winged airplane with an upper and a lower set of wings. The wings themselves are divided into two parts and are referred to as right and left, upper and lower in this type of construction. There is also a small, independent section of wing placed between the right and left parts of the upper wing, attached and braced very strongly to the fuselage or body of the machine. This small piece of wing is called the center section.

When an airman wants to refer to the front or back of anything on an airplane, instead of calling it the "front" or "back" edge, he calls it the "leading" or "entering" (for front) and "trailing" (for back) edge. Therefore, every wing surface, and other part too, has a leading edge, that edge leading or entering the air first, and a trailing edge, that edge that trails behind.

Ailerons.—A small section of the main wing is made as a separate piece and then hinged to the rear, or trailing, edge of the main wing. These small sections are made to tip up or down by the movement of the control mechanism, and are called *ailerons.* On some ships they are attached to the trailing edge of the upper wings only, while on others they are attached to both upper and lower wing sections.

Fuselage.—The next part in importance is that corresponding to the body of an automobile. This is called the *fuselage.* The fuselage was originally called the "nacelle" and is still sometimes referred to by that name. The fuselage houses the pilot, crew and passengers or load, besides the main fuel and oil tanks. Engine, wings, tail stabilizer and control surfaces, landing gear and tail skid are attached to the fuselage. This fuselage is a mighty important part



1. Fuselage
2. Landing gear struts
3. Shock absorber
4. Landing wheels
5. Air-cooled radial motor
6. Propeller, adjustable blades
7. Propeller hub
8. Spinner
9. Exhaust pipe
10. Oil reservoir
11. Fuel tank
12. Cabanne struts (center section struts)
13. Interplane struts
14. Strut connecting ailerons
15. Flying wires
16. Drag wires
17. Landing wires
18. Rudder cable
19. Tail skid
20. Instructor
21. Student
22. Vertical stabilizer or fin
23. Balanced elevator or flipper
24. Balanced rudder
25. Rudder post horn
26. Top wing
27. Lower wing
28. Leading edge
29. Trailing edge
30. Balanced aileron
31. Landing lights
32. Starboard wing light
33. Port wing light
34. Compass
35. Fire extinguisher
36. Tires
37. Compression rib
38. Cambered rib
39. False rib
40. Rear wing beam or spar
41. Front wing beam or spar
42. Longeron
43. Adjustable stabilizer
44. Bulkhead fire wall
45. Control stick levers
46. Rudder bar
47. Turtle-back frame
48. Pitot tube
49. Foot hole
50. Engine throttle
51. Wind shield
52. Diagonal fuselage brace strut
53. Vertical fuselage brace strut
54. Aileron control cable
55. Air vents for wing fuel tanks
56. Incidence strut
57. Streamlined head-rest

Fig. 1.—Sectional view of modern biplane showing principal parts.

of the airplane because all of the other parts are connected together through it.

Tractor and Pusher.—The power necessary either to pull or push the airplane through the air is derived from a gasoline internal combustion engine and a propeller. Engine types are many and varied and will be explained in detail in later chapters.

When the engine and propeller are placed so as to pull the airplane through the air, as in Fig. 1, the plane is called a "tractor" type. When the engine and propeller are placed so as to push the airplane through the air, the plane is called a "pusher" type, Fig. 2.

Fig. 2.—Pusher type Fokker amphibian.

Empennage.—The next important and interesting parts are the surfaces at the extreme rear end of the fuselage. This group is referred to as the "tail surfaces" or "empennage," and is divided into four distinct parts. The parts include the vertical stabilizer, sometimes called the "fin," which is attached to the fuselage and stands up in a vertical position. It acts in much the same capacity as a vessel's keel. Hinged to the trailing edge of the fin is the rudder which controls the directional movement of the plane. The horizontal stabilizer, a fixed surface placed at right angles to the fin and also attached to the fuselage, acts as a longitudinal keel. The elevators, or "flippers," are hinged to the trailing edge of the horizontal stabilizers, one on each side of the rudder, and are for the purpose of controlling the climbing and diving movement of the plane.

Landing Gear.—The wheels, axle and their bracing are called the landing gear, or the undercarriage. A slang name for the land-

ing gear is the "trucks." On most airplanes, especially of the large and heavy class, the wheels are supplied with brakes. Shock absorbers are fitted to the landing gear for the same reason that they are used on automobiles. A considerable jolt is transmitted to the whole plane when first striking the ground in landing or when running over rough ground in taking off. The shock absorbers lessen these shocks by providing a cushion between the wheels and the rest of the machine.

In order to keep the rear end and tail surfaces from dragging on the ground when taking off or landing, a means of holding the tail up a short distance is provided by what is called the "tail skid." On the very large and heavy planes the tail skid is sometimes provided with a wheel. When a wheel is not used here the tail skid is provided with a metal shoe, unless the whole part is made of metal.

Struts.—The rigid braces necessary to hold certain parts together or in their proper relation to each other are referred to as *struts.* The strut braces that hold the upper and lower wings apart are called "interplane" struts. Those holding the center section in proper relation to the fuselage are called "center-section" struts. Those that brace the landing gear are called "landing-gear" struts, those that brace the horizontal stabilizers are called "stabilizer struts," etc. Struts are also used in the construction of the fuselage frame, as vertical, horizontal and diagonal struts. In fact, any rigid bracing other than wire or cable, is called a strut.

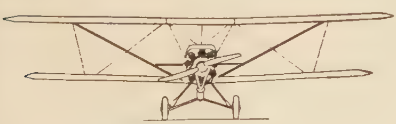


Fig. 3.—Flying wires accentuated.

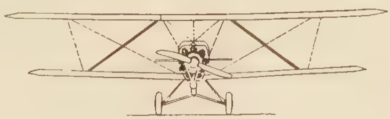


Fig. 4.—Landing wires accentuated.

Wire Bracing.—Wire and cable bracing is used a great deal in biplane construction. Struts are used where a push as well as a pull strain may be exerted, but when only a pull strain occurs, a wire or cable is used to reduce weight but still provide sufficient strength. Some of these wire braces have distinguishing names while others are called just bracing wires, prefixed by the name of the part that they brace. Referring to Fig. 3, you can see the "flying wires"

outlined by heavy lines, and the "landing wires" are outlined heavily in Fig. 4.

They are called flying wires because they are in use while the airplane is flying. The pressure of the wind, of course, pushes the wings up, gravity tending to draw the fuselage down. The purpose of the wings, therefore, is to overcome gravity and hold the fuselage suspended in the air. If the wings were just bolted to the fuselage with no other bracing to hold them, the pressure of the wind pushing up would tend to push the wings up, as in Fig. 5. But wire braces are put in place, as shown in Fig. 3. Then as the wings tend to fold up, they are kept from doing so by the flying wires fastened between the fuselage and the outer edge of the wing. In this way the weight of the fuselage is lifted in the air through the flying wires.

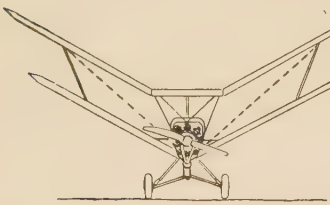


Fig. 5.—What would happen with no flying wires.

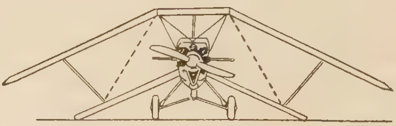


Fig. 6.—What would happen with no landing wires.

The other wires are called the landing wires, because they are in use while the airplane is landing or is at rest upon the ground. When at rest upon the ground the weight-supporting part is the landing gear, whereas it is the wings while the plane is in the air. The landing gear wheels resting on the ground directly support the weight of the fuselage. Were the wings just bolted to the fuselage, with no other bracing, their weight would tend to cause them to droop to the ground, as in Fig. 6. But wire braces are put in place, as shown in Fig. 4. Now, as the wings tend to droop to the ground, they are kept from doing so by the landing wires fastened to the upper end of the center section struts and to the lower end of the outer inter-plane struts, thereby keeping the wings up in place. Brace wires are used in several other places and will be explained as we come to them.

The parts discussed are those of a typical tractor biplane, except for the control levers. These levers are in the pilot's cockpit and comprise the rudder bar, a stick, or stick and wheel, and the engine controls of throttle, spark and gas mixture. Instruments, used for both navigation and in checking engine performance, are rightly airplane parts, also, and will be described later.

AIRPLANE TYPES

There are many, many airplane types, if all the freak designs are to be classed as types. We shall consider only those types that have proved themselves worthy of the name "aircraft."

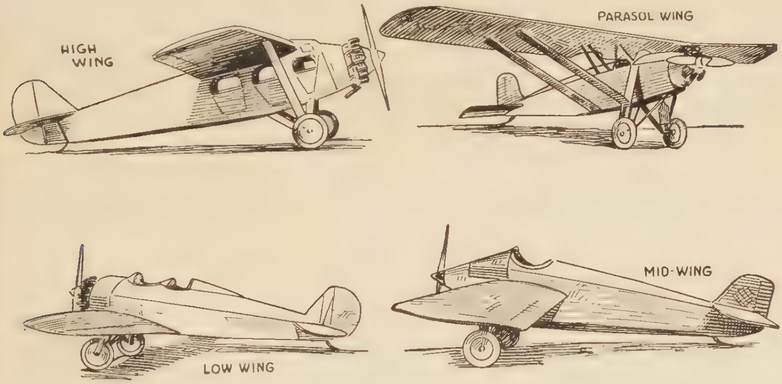


Fig. 7.—Several monoplane types.

First, there are two distinct classes of aircraft, lighter-than-air and heavier-than-air. The lighter-than-air types depend for their support in the air on displacing air with a gas lighter than air, contained in a confining envelope. This class includes the ordinary balloon, the semirigid "blimp," which is really an oblong balloon, and the dirigible which is a rigid metal frame housing balloons in sections. These balloons are built so that their shapes conform to one another, making one huge balloon divided into sections. The dirigible type is driven through the air by internal combustion engines and propellers and is guided by control surfaces. This machine needs a number of men for its successful operation, both while in the air and in landing. It is used chiefly for military or large commercial work.

The heavier-than-air class is divided into several types, one of which is the *monoplane*, an airplane having a single wing on each side of the fuselage. The monoplanes are again divided into four classes. One class is called the *parasol*, with the wing placed a short distance above the fuselage and anchored to it by struts and braces, as shown in Fig. 7. Another monoplane type is the *high-wing*. In this plane the wing is fastened directly to the top of the fuselage. In the *mid-wing* type the wing is fastened midway between the top and bottom of the fuselage. The *low-wing* monoplane has the wing attached to the lower fuselage member.

A *biplane* has two wings, one above the other and extending out from each side of the fuselage. A *triplane* has three wings similarly placed, and a *quadraplane* has four wings placed one above the other. The biplane first proved the favorite all-around efficient aircraft, but the monoplane is fast gaining that favoritism. Triplanes are in very little use and quadraplanes even less.

Any of the above types may be of the land plane type, using wheels for landing and taking off from land, or of the seaplane type, Fig. 8, using one or more small buoyant hulls, called pontoons, which enable them to land on or take off from water.

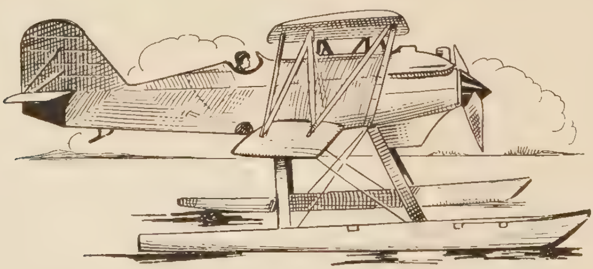


Fig. 8.—Biplane seaplane.

Another type of airplane is that which is provided with both a buoyant hull and wheels and can operate from either land or water. This type is called the *amphibian*, illustrated in Fig. 2. By a controlling device the wheels can be raised out of the way for water operation and lowered into place for land operation.

Multi-engines.—On very large airplanes more than one engine-

propeller unit is sometimes used. These units may be all tractor types and sometimes may combine the two types, tractor and pusher. The most popular design of multi-motor airplanes use three tractor units, one mounted in the nose of the fuselage and one suspended under each wing by struts. The motors mounted on the wings are called the "outboard" motors. The Ford trimotor plane, Fig. 9, is an example of this construction.

Fig. 9.—Tri-motor Ford transport.

Occasionally a tandem arrangement is used, but very seldom. This means a tractor and a pusher unit mounted one directly behind the other, or in tandem. This allows of easy construction, but unless the rear unit is of more power than the front unit it will be very inefficient, due to its working in disturbed air, or in the "wash" (wake) of the front engine.

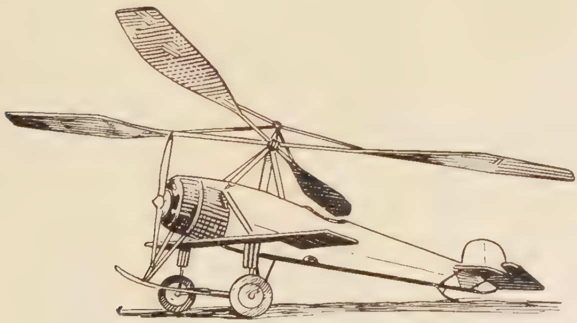


Fig. 10.—Helicopter.

Some large military bombers mount an engine on either side of the fuselage only, thus allowing clear vision for the forward observer. The greatest disadvantage of this design lies in the fact that one engine would not be able to fly the plane in case of failure of the other. If this happened the operating motor would tend to pull the machine around in a circle with the working motor on the outside of the circle.

A very distinct type of airplane is one designed to rise straight up and come straight down under control. This is called a *helicopter* and uses a huge light-weight propeller mounted horizontally above the fuselage, as shown in Fig. 10. This propeller is made to revolve rapidly and is supposed to lift the machine into the air and then the conventional tractor propeller supplies forward motion. A desired height is maintained by slowing down the horizontal propeller until it just holds the machine at the required height. Further slowing down would allow the plane to settle down and increasing propeller speed would cause it to climb.

CHAPTER III

THEORY OF FLIGHT AËRODYNAMICS

IN order to understand why airplane parts are shaped as they are it is best that we follow Da Vinci's system and learn something about the airplane's element—air. Airplane wings, as well as other parts exposed to the wind, are carefully shaped to take advantage of every bit of support offered by the air, and unless we have at least a slight understanding of the effect of air on moving surfaces, the reason for these various shapes would be rather indefinite in our minds.

Definition.—The study of the action of air is called *aërodynamics,* a difficult sounding word which becomes most simple when it is understood that the "dynamic" part of it means no more than the effect of certain things which change the motion of other things. The certain things that cause the change are forces of different kinds. The prefix "aëro" means air. Therefore, putting them together, we have aërodynamics and that means the effect of forces in the air on the motion of things—airplane parts.

Air Properties.—Scientists consider air as a fluid. Air is also a form of gas, composed of a mixture of twenty-three per cent oxygen and seventy-seven per cent nitrogen. It is the oxygen part that produces combustion or explosion under certain circumstances. No good purpose has as yet been found for the nitrogen in an internal combustion engine except perhaps to dilute the highly energetic oxygen. But to get back to air as fluid. A fluid is defined as anything in which the minute particles can be moved about easily but still keep together in a general way. Gases as well as liquids are fluids because the minute gas particles move about easily but still keep together in a general way when they are pushed.

Air, unlike a wet fluid, can be compressed and it tends to hold together. Inhaling through a straw proves this latter statement. As you suck the air out of the straw more air immediately takes

its place, coming in the other end, because it will not permit a vacuum or a place of no air to occur—it tends to hold together. Air also has weight.

Density and Weight.—In order to demonstrate how air has weight, let us remember that there is air (oxygen and nitrogen gas) surrounding the earth and it is acted upon by the force of gravity. The distance away from the earth to which this air extends has not been definitely determined, but it is known to be still in evidence at around 43,000 feet as proved by an actual balloon ascension. This tremendous altitude was gained by Captain H. C. Gray in a United States Army balloon. At this altitude there is not enough oxygen to sustain life in a human being, and concentrated oxygen is taken along to breathe. But anyway, knowing that there is air of that depth weighing down on the earth, it is easy to understand that eight miles, or more, of this gas being supported by the air near the earth's surface exerts some weight. This air above compresses the air underneath to a greater and greater degree as the earth is approached, and this weight pressure of air is called density.

There are certain characteristics of air that have been discovered and proved by scientific instruments. One is that air at a temperature of 32° F. at sea level weighs .0807 pound per cubic foot, which is about one and one-third ounces. This is supposing that the air is dry—moist air weighs still more.

The weight and pressure of air decrease as the height above sea level increases. At one mile above sea level the weight of one cubic foot of air is decreased to .0619 pound, and at five miles it weighs only .0309 pound. The pressure at sea level and at 60° F. of 14.7 pounds per square inch drops to 6.87 pounds pressure at 20,000 feet. This is because of the fact that there is not so much air above pressing down on the lower strata.

The fact that air changes its density at different altitudes varies the performance of an airplane at different altitudes; the support of the wings is lessened and the motor is affected greatly because of the impossibility of taking in as much fuel per revolution of the engine at high altitudes, with the result that the power is lessened as altitude is gained.

For instance, at 1,000 feet altitude, the air density is .0734 pounds per cubic foot as against .0761 pounds at sea level; the

pressure per square inch is reduced to 14.088 pounds as against 14.701 at sea level. At 5,000 feet the density and pressure per square inch have reduced to .0632 pounds and 11.956 pounds respectively. This fact results in an engine delivering only 95 per cent of its rated horsepower at 1,000 feet and 80 per cent at 5,000 feet. The density and pressure of air continues to change as altitude increases, and engine horsepower, together with the lifting ability of a given surface, consequently is reduced.

Because air has weight and moves around in what are called air currents and wind, it offers resistance and applies a force to objects in contact with it. Elements that have to do with this resistance and force are:

Elasticity—the tendency of air particles to go back into a space from which they have been removed.

Viscosity—the quality in a fluid that is called friction when referring to anything solid.

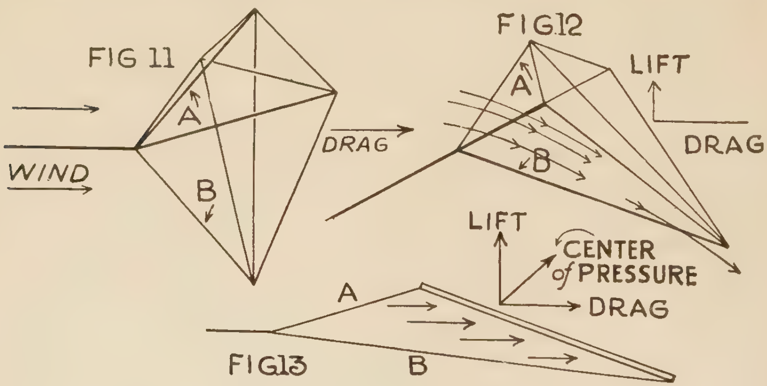
Inertia—common to all matter in which all bodies at rest tend to remain at rest, and all bodies which are moving tend to continue moving. There is a resistance always against any attempt to change either this state of rest or state of motion. It takes force of some sort to overcome inertia—force to move a standing object and force to stop a moving object.

Due to the inertia when air is in motion, it exerts a force on any obstruction that tries to hinder its motion. Air striking the sails of a boat exerts a force and drives the boat through the water.

Relative Wind.—One of the terms used in aviation with which you should be familiar is "relative wind." Air in the form of slow currents or wind of high velocity flows past objects. The object may be stationary and the wind flowing past it, or the air may be stationary and the object moving past it. In either case the velocity of the wind relative to the object is the same and any air so passing an object is called the "relative wind." The direction and speed of the wind passing an airplane is the direction and speed of the relative wind and has nothing to do with the direction and speed of the wind on the ground. The ground has nothing whatever to do with the speed of a plane through the air. In considering the airplane the ground is only a place to keep it when it is not flying.

Air Currents on Flat Surfaces.—When you were a boy flying a kite, you noticed the action of the kite under different conditions of attaching the string, and perhaps you can recall some of these actions if I remind you of them.

Referring to Fig. 11, if the strings *A* and *B* are of the same relative length as shown, the wind indicated by arrows striking the kite would exert a force tending to move the kite in the direction of the wind. The kite presents a surface tending to obstruct the flow of air. The main string being held, the kite cannot get away and remains stationary in relation to the ground, but not in relation to the wind because the wind is flowing past it just the same. You used to want the kite to go up so the string *A* was made slightly



Figs. 11, 12, 13.—Action of relative wind on kite.

shorter than *B*, thus tipping the kite into the wind as in Fig. 12. This resulted in deflecting the wind current downward and the kite upward in the direction of *Lift*. In Fig. 13 the string *A* has been shortened still more, and in consequence the kite is more horizontal in relation to the ground. Besides the lifting force, there is also a force tending to drag the kite along with the wind. Part of this force is air pressure and part of it is viscosity or skin friction, and the two such forces are called the drag of the surface. This drag is overcome by the force exerted by the holder of the string.

But the relative wind passing the kite not only exerts a pressure on the front surface, it also creates a space at the rear where

the density is less, a partial absence of air. It is not possible for the air instantly to reoccupy the space from which it has been displaced by the passing of the kite. This results in a partial vacuum at this point. This vacuum tends to suck the kite backward in order to fill the space. What really happens is not the vacuum sucking as much as it is the pressure in front meeting absolutely no resistance to its force. If this air were photographed, as it is in aërodynamic laboratories, it would look something like that in Fig. 14, when we looked at a direct profile of the kite.

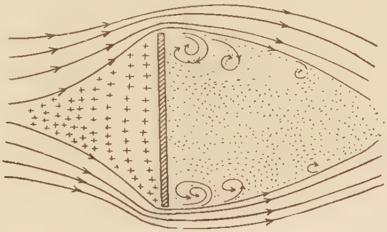


Fig. 14.—Effect of air on a flat surface.

The air stream divides and goes around the edges of the kite to come together again at a point in the rear, the distance depending upon the speed, or velocity, of the air stream.

Many imagine that the air *pressure* on an object under these circumstances provides the force to lift it, but it has been proved otherwise; the vacuum at the rear provides about sixty to seventy-five per cent of the lifting force.

Action of Air on Cambered Surfaces.—In very early airplanes the wings were made straight and flat, until some experimenter discovered that by curving the surface from leading to trailing edge it would produce more lift for the same area of wing. This curving is called *camber* and is illustrated in Fig. 15. This discovery opened a fertile field for experiments and wing shapes became varied, using camber in various forms.

It has been found that air will do certain things under certain circumstances. This fact has a great deal to do with designing wing and control surfaces, in fact, with all parts of an airplane. For the purpose of grouping parts, all wing surfaces and control surfaces

are called airfoils. The airplane wings are its supporting parts and naturally the greatest care is taken to shape them so as to direct the air stream passing them into paths that will produce the desired results.

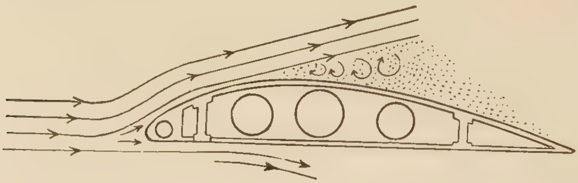


Fig. 15.—Effect of air on a cambered surface.

Investigation of the air path around a cambered wing has shown that the air is split, as shown in Fig. 15. If the under surface is left straight the air exerts a certain pressure underneath. If the upper surface is cambered the air is deflected up, leaving the upper surface altogether and producing a partial vacuum there that tends to suck the wing upward. This is how three to four times as much lift is exerted on the upper surface as is exerted on the under surface by the pressure.

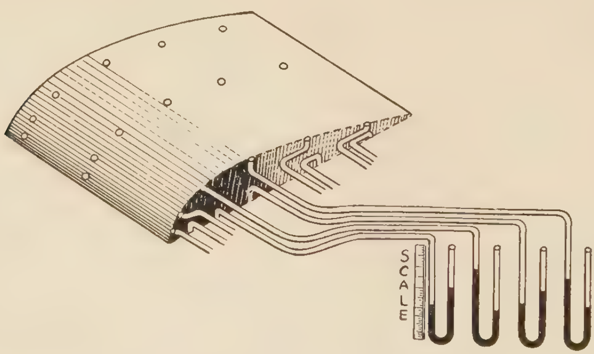


Fig. 16.—The use of manometers.

Manometer Tests.—These and other important facts have been discovered by the use of *manometers.* A manometer is a glass tube bent into a U shape with a liquid in the bend. If you should exert a pressure or blow on one end of this tube, the liquid in the

other end will rise. If you create a vacuum by suction on one end the liquid will drop in the other end.

The manner in which manometers are used to determine the pressure and suction acting on a wing surface is shown in Fig. 16. In Fig. 15 it is shown that the relative wind passing over the top surface exerts a vacuum suction and this is called "negative pressure." The relative wind at the same time exerts a pressure or push on the under surface; this is called "positive pressure." With manometers attached to both upper and under surfaces it is possible to measure the total pressure, both negative and positive, being exerted on the airfoil at different angles of attack and at different speeds. In this way the proper shape, to a certain extent, can be determined to get the desired results.

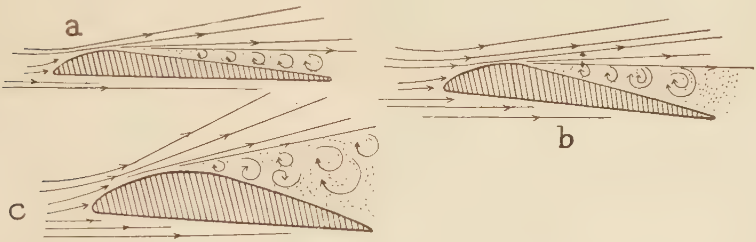


Fig. 17.—Air travel over different cambers.

Effects of Camber.—Fig. 17 illustrates three different shapes of camber and the path of the air around them, supposing that they were entering the wind horizontally and not tipped upward at any great angle. The under side of the wing has very little curve, sometimes being perfectly straight. The upper illustration *a* is of a wing with comparatively little camber. The result is that it can be made to move forward with but little power but requires speed to produce lift. A shape similar to this will be found on high-speed racing planes and military pursuit planes.

The illustration *b* is of a wing with a greater degree of camber which offers more drag than *a* but deflects the air upward at a greater angle, creating a greater negative pressure and a consequent greater lift. This type of shape will be found on planes intended to lift a fair load and travel at a fair speed.

Illustration *c* is of a wing with still greater camber which, by deflecting the air upward at a still greater angle, produces still more lifting power but is beginning to offer a considerable drag on account of disturbing the air to such an extent.

There is, of course, a degree of camber beyond which all benefit would be lost and the drag would overcome the lift, each exactly counteracting the other. But long before this stage is reached the size of the wing, or area, is increased if more lifting power is desired. Adding more wing area by increasing the wing size will provide more lifting surface, but this also adds weight both by increasing the wing material and bracing. Besides additional weight the larger wing also presents more friction drag surface to the wind. In view of all these factors, a very fine line of desirability must be drawn between increasing camber and increasing area.

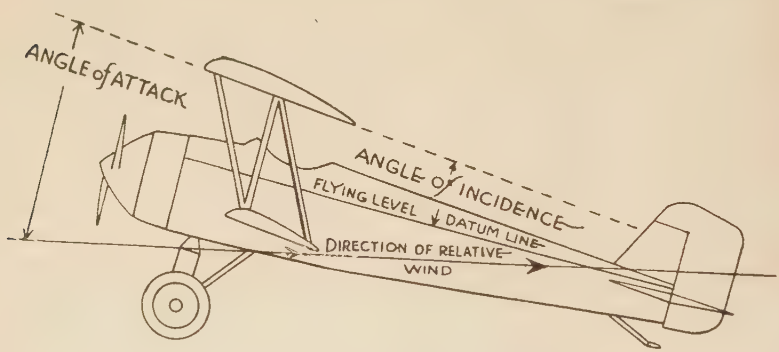


Fig. 18.—Angles of plane surfaces illustrated.

Angle of Attack and Angle of Incidence.—The angle at which the wing surface meets the air, as in climbing or diving, is called the angle of attack, Fig. 18. The wing surface is attached to the fuselage so that when the airplane is in its position of normal level flight the angle of attack is sufficient to suspend the machine in the air. This angle changes as the controls are moved to lower the tail, thus meeting the air at a greater angle when climbing.

The angle of the wing in relation to the fuselage is called the angle of incidence. Do not confuse these two angles as they are referred to many times in aëronautics, sometimes wrongly, by some

writers who persist in referring to the angle of attack as the angle of incidence. The angle of attack is variable through controlling the position of the airplane. The angle of incidence is not variable and remains the same in relation to the fuselage whether the plane climbs or dives.

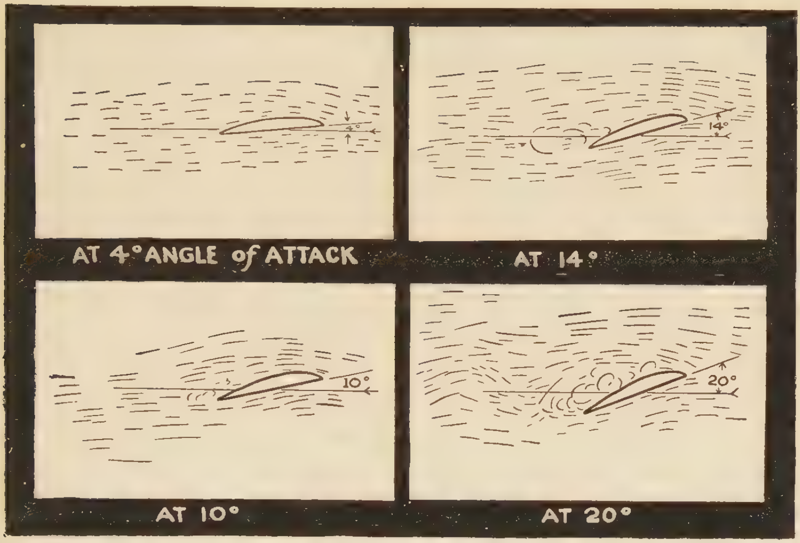


Fig. 19.—Air travel over surface at different angles of attack.

Fig. 19 illustrates air currents passing an airfoil at different angles of attack. As the angle increases air eddies, or "burbling," increase on the upper surface. To a certain degree these eddies are effective and create a suction, but beyond a certain point they are called burbles and become ineffective. This latter point is also called the angle of maximum lift, and any increase beyond will remove all lift and it is then called the stalling angle.

You might suppose that increasing the angle of incidence would produce more lift by consequently increasing the normal angle of attack. It will up to a certain degree. But the advantage in lift is quickly overcome by the increase in drag and it has been found that

a 5° angle of incidence is as great as can be used with any efficiency. Beyond this angle the efficiency drops rapidly.

Center of Pressure.—If a flat plane or plate were held directly perpendicular to the wind, the force exerted on it would be equally distributed over its surface, therefore there would be a center point of pressure, a point where the total force might be considered as centered. This point is called the center point of pressure, or center of pressure, and is illustrated at *a*, Fig. 20. It would be possible to balance the plate in the wind stream by holding it with a knife edge as shown, exactly in the center or at the center of pressure. Now, if it were desired to tip the plane into the wind, or horizontally, so as to force the plate up, the knife edge must be moved up on the plate, as at *b*, Fig. 20, and in such a position the center of pressure has moved upward and forward. The farther the plate moves toward horizontal the farther forward the center of pressure moves; in other words, the less the angle of attack the farther forward is the center of pressure, the greater the angle of attack, the farther back the center of pressure moves.

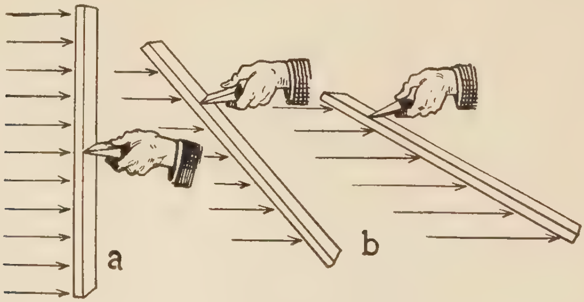


Fig. 20.—(a) Center of pressure; (b) Center of pressure movement.

The same effect takes place on the airplane wing. The center of pressure is continually moving as the angle of attack is changed in climbing or diving. The wing is held at its angle of attack by being attached rigidly to the fuselage in which the weight is made to balance the force acting on the wing. If lines were drawn to represent the forces acting on the upper surface of a wing, they would be like those of the lower illustration in Fig. 13—the lift being

straight up, the drag being straight back and the center of pressure being midway between the lift and the drag. The effect on the complete plane as the center of pressure changes on the wing will be explained later.

Lift Distribution.—The highest efficiency, which means the greatest lift with the least drag, is, of course, the aim of every aircraft designer and engineer. The shape of a wing, other than the camber, also has a lot to do with the efficiency. If you have seen and inspected airplanes very closely, you will have noticed that wing tips have different shapes in different planes.

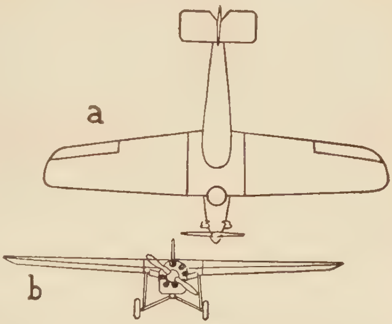


Fig. 21.—(a) Reduction of chord toward tip; (b) Reduction of camber toward tip.

If a wing were perfectly uniform in shape over its entire area, there would be an equal amount of lift exerted over the entire surface. The result would be that a terrific leverage would be exerted, increasing as the tip was approached, and most of the lift would be thrown on the tips, a very bad condition. For this reason the lifting force is reduced as the tip is approached through changing the shape as to camber, angle of incidence and area. Fig. 21 illustrates a combination of two of these changes. The upper part of the illustration, *a*, shows a plan view of a wing tapering as it reaches the tip, thereby reducing the area and consequently the lift. The lower part of the illustration, *b*, is a profile of the same wing showing a reduction in thickness and camber.

Different wing tip shapes have been experimented with, using manometers to determine the lift distribution. Fig. 22 shows four differently shaped tips and the fine lines on them follow points where lift was found to be equal. The two raked tips show lift as being bunched at the outer corners, the weakest point of a wing. The square and elliptical ones show a more even distribution, the elliptical perhaps a little better than the square.

On airplanes required to carry heavy loads increased camber and area will be found in the wings. The Ford trimotored transport

carries 12.74 pounds to the square foot of wing area. The Boeing mail-cargo model 95 plane carries about 12 pounds to the square foot. Ships built for speed alone will have less camber and less area, sometimes not carrying over five pounds to the square foot.

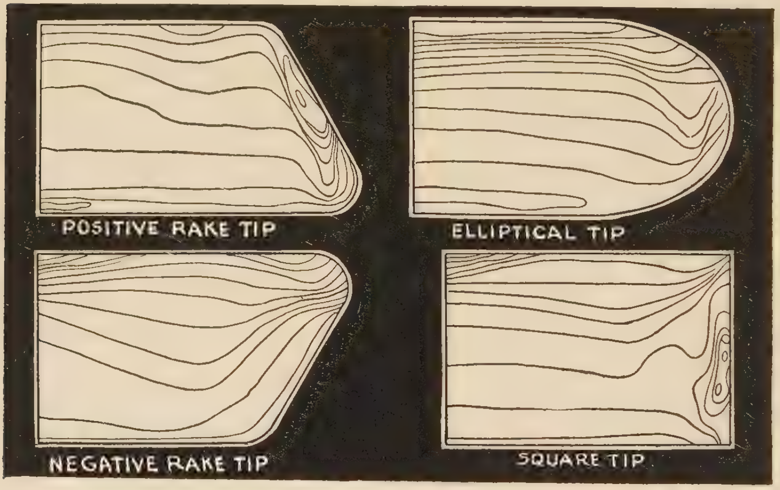


Fig. 22.—Wing tip shapes.

You may have seen an airplane leave the ground, and wondered how the lifting force is gained so quickly. It seems to run over the ground and then, with no great increase in speed, lift itself off. Lifting forces, including vacuum, do not increase in direct proportion to the speed of the relative wind, but at a much higher rate. If the speed is doubled, the wings do not only meet twice the volume of air, but also meet it twice as fast. Therefore the resulting effect is four times as great as at the first speed—twice the volume at twice the speed. The lifting force, therefore, varies as the square of the velocity, and the drag also increases rapidly with a small increase of velocity. The area of a surface has a great deal to do, also, with forces exerted upon it, both as to lift and to drag.

Aspect Ratio.—The shape of a wing in regard to its length and breadth has considerable effect on the lift of the wing. It has con-

siderable effect on the resistance or drag of the wing. The relation of the length of the span to the width of the chord is called "aspect ratio." For example, if the span of a wing (distance from tip to tip) were fifty feet and the chord (distance from leading edge to trailing edge) were five feet, it would have an aspect ratio of ten because the span is ten times the chord.

Drag increases considerably with increase of aspect ratio—in greater proportion than lift. For this reason aspect ratios are usually confined to between four and eight and one-half. If a greater ratio than eight and one-half were used, it would necessitate a thicker wing section to house the added bracing necessary. If the thickness were not used the bracing would have to be placed outside—both providing added drag. But this is a matter of more interest to designers than to us.

Skin Friction (Viscosity).—There is a certain amount of friction between an object and the air passing that object. When you move a piece of cardboard flat against the air, as at *a,* Fig. 20, you feel a resistance, a drag. When you move the same cardboard edgewise through the air you would say that all resistance is eliminated—but there is still some resistance, however small, due to the air rubbing over the surface of the cardboard. This resistance is called *skin friction,* hardly noticeable on a small surface, but over a large area it increases to a considerable extent—the exact amount depending upon the area and the smoothness or roughness of the surface. This skin friction is taken into consideration in figuring the total drag of a surface. To eliminate this friction as far as possible, exposed airplane surfaces are treated to produce a smooth, glossy finish.

Streamline.—You can see that there are many things trying to hold an airplane back as it flies through the air and so many other things are done to overcome this dragging effect. You already know that air offers a resistance when an attempt is made to disturb it. It is very easy to understand, then, that a great deal of air is disturbed when an airplane rushes through it and a certain amount of resistance results. In some cases the air is guided into certain channels for the purpose of exerting the greatest lifting force possible.

A great many parts of the airplane disturb air and provide drag

with no lift. This kind of drag is called "parasite drag." It is possible to shape some of these parts to reduce the drag without reducing the strength of the part.

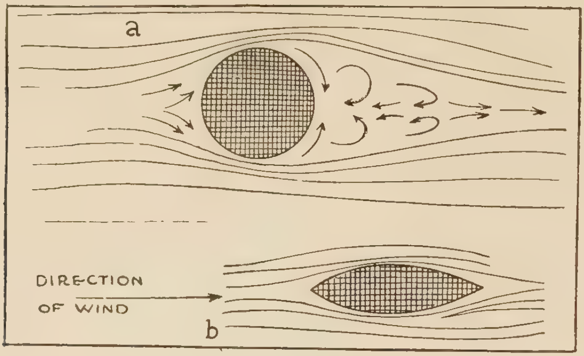


Fig. 23.—(a) Air passing a round object; (b) Air passing a streamlined object.

Suppose we assume that an interplane strut were round, as illustrated in *a*, Fig. 23. The lines illustrate the path of the wind passing the strut. It can be seen that there is a certain amount of pressure exerted at the front due to the crowding away of the air. There is also a certain disturbance at the rear of the strut. If the air were divided more gradually in front and the space filled at the rear where commonly there is nothing, the vacuum, the pressure in front and the vacuum suction at the rear would be reduced to such an extent that it would be hardly noticeable. A part shaped like that shown in *b*, similar to a fish, does just this and is then said to be "streamlined," meaning shaped like an air stream. When all parts that possibly can be are streamlined, the drag is eliminated to such a degree that ten to fifteen miles an hour is added to the speed of an average airplane.

Forces Acting on an Airplane.—There are four forces continually acting on an airplane while it is in the air, two positive and two negative. The two positive forces are lift and thrust. The lifting force is derived from the wings and tends to suspend the machine in the air. The thrust force is derived from the engine propeller which tends to force the machine forward through the air.

The two negative forces are drag and gravity. The drag is caused by the air friction on the surfaces and the resistance of the air against being disturbed. The drag is opposed by the thrust. Gravity is caused by the attraction of the earth and is opposed by the lift.

Now you can see that the airplane designer has a great many more things to consider than has the automobile designer. Lifting ability is the most desired quality for the load carriers, the commercial transport type built to carry express, mail or a number of passengers. This ability necessitates a higher powered engine or engines than are used in the small high-speed sport type of plane where lift is not so important.

Center of Gravity.—While in the air an airplane has no solid support other than the air cushion under the wings. Therefore all surfaces, wings and stabilizers, must be placed exactly right so as to provide an even balance. Just as there is a center of pressure, so there is a center of gravity—a point on the plane where if a knife edge were placed the whole machine would exactly balance fore-and-aft and sideways or laterally.

Imagine a seesaw on one end of which is a heavy boy, on the other end a light boy. If the supporting medium of the seesaw were placed directly in the center, the weight of the larger boy would overbalance the lighter boy. In order to cause the lighter boy to balance the heavier it is necessary to place the support nearer the heavy boy, thereby providing the lighter one with leverage. The point where the support is placed for this result is the center of gravity.

Wind Tunnel.—An apparatus for testing the effect of moving air on wings, control surfaces and also complete airplanes is called a "wind tunnel." A wind tunnel may be as large or as small as the available space will permit. It is a large tube, Fig. 24, through which air is drawn by a propeller, run usually by an electric motor, and placed at the discharge end of the tunnel. Placing the propeller here has been found to create an evener flow than when the air is pumped into the tunnel. The U. S. Government wind tunnel in the Aviation Experimental Laboratories at McCook Field has a throat five feet in diameter. This throat is called the "experimental chamber" and the models under test are mounted in it on

very delicate instruments that measure the lift and drag produced on the model.

Proper streamlining, camber and shapes are determined by tests conducted in the wind tunnel and offer a deep study of physics and higher mathematics, so let's concede that the designers know what they are doing and be concerned only with the results they obtain. What I tell you of the action of air on wing surfaces and of the path followed by air under certain circumstances you may take as facts because proofs of them have been established in these wind tunnel experiments.

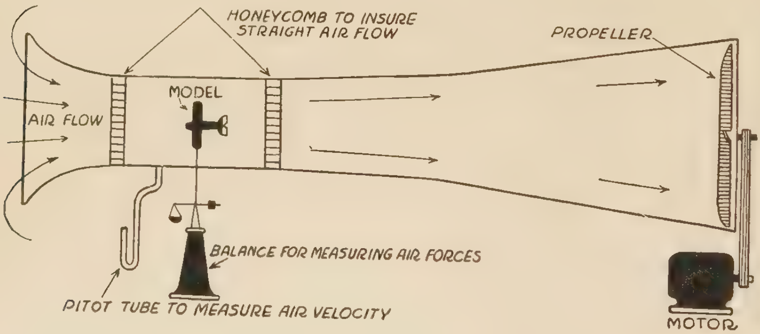


Fig. 24.—One type of wind tunnel.

Theory and Practice.—All the wind tunnel experiments and the manometer tests supply only theoretical data. And aëronautics is one science where theory and practice have not kept pace with each other. In the majority of mechanical sciences theory has usually paved the way for practice, but in dealing with aëronautics, the opposite is more often the case. Most of the advance in construction has been made by an intrepid experimenter going ahead and building a full-sized conception of his idea and testing it under actual flying conditions. Many a theory, sound in fundamentals and showing good performance in the wind tunnel, has proved absolutely worthless in actual practice.

Away in the beginning of aviation one wing was used, and then someone figured that two wings would offer twice the lifting force. So the biplane came into being. This worked pretty well, so theory

asked why wouldn't still more wings work still better. So triplanes and even quadraplanes were tried out. But in actual practice it was found that with each addition of a wing, the whole airplane became less and less efficient.

The biplane settled down to be the accepted style and any less than two wings was not considered enough to hold an airplane in the air and provide enough lift at low landing speed. But what did Lindbergh use? A monoplane! A single-winged monoplane has demonstrated that it will do certain things better than a biplane; a biplane will do certain things better than a monoplane. These things have not been worked out by theory, but by actual practical experiments.

The wind tunnel has established certain basic facts, such as camber being better than a straight surface, that streamlined shapes offer less resistance, etc. But due to the very complication of aërodynamics, no accurate mathematical formula has been perfected whereby shapes and contours can be absolutely calculated to obtain a certain result. Many a model, having all the lines and the shape of supposedly perfect ships, has performed in the wind tunnel wonderfully. But when a full-sized ship made from this model has taken to the air, it has performed anything but wonderfully. To cite my own experience along this line, I cannot remember a time when I have taken up a new machine, rigged and put together exactly to specifications, and found it to perform as it should. The wings, tail surfaces and fuselage had been placed in exact relation to each other according to theory, but before it "felt right" or flew properly, I have had to alter angles and wires each time.

Consider the experiments conducted with monoplanes. This type was first constructed with the fuselage hanging by strut bracing from the wings. This was done because the lift was supposed to be derived from the wind pressure on the bottom of the wing. The plane was "touchy," unstable and could not be braced strongly enough. So then the wing was mounted on top, but directly attached to the fuselage. This offered more rigid construction but offered an obstruction to the pilot's view. Theory easily overcame this objection by mounting the wings on the lower part of the fuselage, forming the low-winged machine. But this machine was found to cause certain undesirable conflicting air currents with the

ground when taking off, besides reducing the upper lifting surface area by inserting the fuselage between them. To overcome this disturbance of the wind and ground, the wing was then mounted midway between the top and the bottom of the fuselage. The accepted construction has finally come back to the high wing in the monoplane type.

So you see that all desirable qualities cannot be built into one airplane; if some are used others must be sacrificed. The final construction has boiled down to the high-wing monoplane which requires a high speed to take off and land, due to reduced lifting area, but attaining a high air speed due to less drag area and less weight. The other accepted construction is the biplane with less speed required for take off and landing, due to greater lifting area, but not attaining the greater air speed because of the added drag area and weight of more wings.

CHAPTER IV

DETAILS OF AIRPLANE CONSTRUCTION

THE method of construction varies in the many different kinds of airplanes. Wings are all manner of shapes both as to camber and plan shape. Tips differ as to shape, both camber and angle of incidence vary, and the chord length will also vary. The selection of the proper wing shape for any desired performance cannot be made without a detailed study of the results obtained by the various shapes.

The performance that would be ideal, of course, is that of a helicopter going straight up and straight down under absolute control, then after the desired altitude is reached, the ideal should combine this ability with that of a regular plane and start off on a straight horizontal line of flight at any desired speed. Add to these qualities the ability to maintain an even keel with the least effort exerted on the controls. So far the airplane has not reached this degree of perfection and certain desirable qualities must be sacrificed in order to obtain others of greater importance.

The qualities most desired, considering the existing drawbacks, are:

1. The highest possible flying speed.
2. The lowest possible landing speed.
3. The least amount of weight and drag.
4. The greatest rate of climb.
5. The ability to carry the desired load.

As to speed, it has been found that the small, high-speed, military pursuit plane has a maximum flying speed of about three times its landing speed—while in the transport type of plane, the maximum air speed is about twice the landing speed.

WINGS

Considering the desired results, one of the most important parts of the airplane in both design and construction is the

wing. The wing not only must be shaped properly to deliver the highest efficiency for the particular work to be done, but must also carry the entire weight of the ship while it is in the air by transmitting the air pressure exerted on it to the fuselage. The wing has been made to possess remarkable lightness but still retain a great degree of strength. While the fuselage frame and some other parts are being made of metal tubing, the wing frame has been found much more satisfactory and efficient if made of wood. Wood has a certain flexibility and toughness found necessary for wing construction.

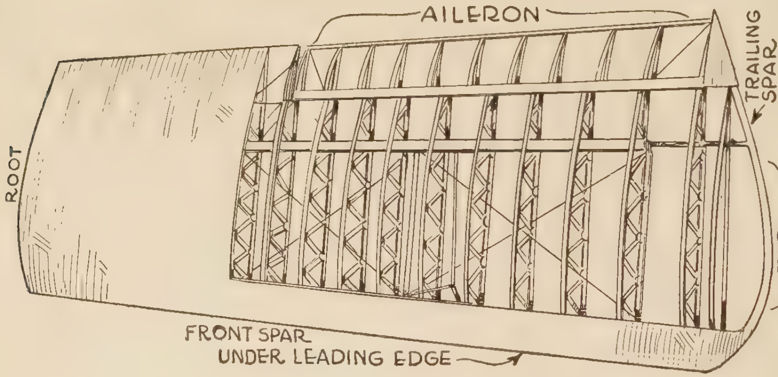


Fig. 25.—Interior construction of a typical wing.

Spars.—The backbone of a wing consists of two comparatively strong, heavy spars running parallel to each other and at right angles to the fuselage, the long way of the wing, Fig. 25. The front spar receives most of the work thrown on the wing both from air pressure, lift and drag. For this reason it is often made up of three or more parts. The center part is sometimes a strip of ash in the form of an I-beam, on each side of which are attached strips of spruce. There are many other types of spar construction, however, each having its advantages with the principle of lightness in weight combined with strength paramount. Several are illustrated in Fig. 26.

The rear spar does not necessarily have to be as strong as the

front spar, and due to the reduction in camber as the trailing edge of the wing is approached, it cannot be as large.

That end of the spar which is next the fuselage is called the root, and the outer end, farthest away from the fuselage, is called the tip. The same names apply to a complete wing. Fittings are attached to the spar roots that permit attaching of the wing to related fittings on the fuselage.

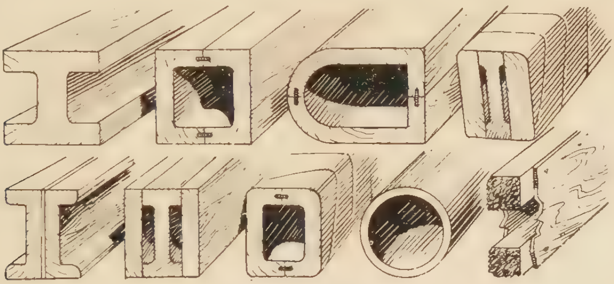


Fig. 26.—Types of spar construction.

The load placed on the spars will vary with a change in the angle of attack. The center of pressure, or center of load, as it may be called, travels back and forth as the plane climbs or dives. At times the load may be equally distributed between the spars, while at very acute angles either spar may carry the total load.

Ribs.—Acting as spacers for the spars and as support for the wing covering are the ribs placed at right angles to the spars. The ribs are very important parts of the wing because their shape governs the entire shape of the complete wing. The rib shapes differ at different points along the wing, depending on the camber and angle desired. The ribs, like the spars, are also made up of three or more parts. The center upright part, called the web, is sometimes made of cottonwood, poplar or whitewood. Strips of spruce, called flanges, are attached to the top and bottom edges running the full length of the rib. The shape of the nose, or leading edge, is very important because this is the point that splits the air first and directs it over the remaining surface. The trailing edge of a wing is sometimes made of oblong metal tubing, and sometimes of a cable

running parallel to the spars and fastened to each rib tip. A popular style of rib construction is shown in Fig. 27.

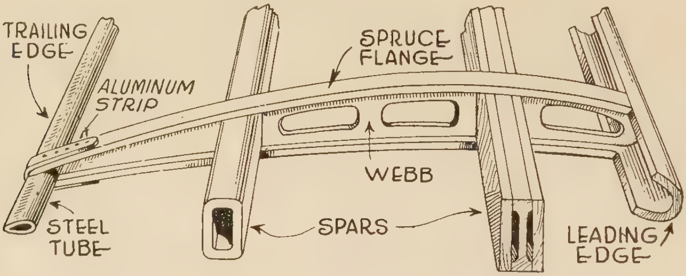


Fig. 27.—Rib shape and construction.

Due to the great air pressure at the leading edge tending to press the fabric covering down on the upper surface and up on the under surface, small sub-ribs are sometimes placed between the main compression ribs in order to support the fabric more rigidly. Some leading edges are made of laminated wood to form the exact shape of the entering edge and running parallel to the spars the full length of the wing.

The ribs are naturally rather weak sideways and in some designs thin strips of lath are placed over them, running parallel to the spars, to brace them against side stresses.

All spars, ribs and other parts of a plane are hollowed and routed out for lightness. The weight is also reduced in any other way possible consistent with strength. The wing frame is then trussed with wire bracing, holding the complete structure together in a light, rigid and strong member.

Wing Dimensions.—The camber shape of a wing is designated by a number and visualized by a profile drawing just as though it were cut through vertically from leading edge to trailing edge. This type of drawing is called a "wing section."

In the majority of wings today the upper surface is well curved and in some cases the under surface is also slightly curved—very slightly in most cases.

Fig. 28 illustrates a wing section divided as is the method when dimensioning the curve of camber. The chord is divided into equal

spaces, usually ten, and the dividing lines numbered, starting at the leading edge with No. 1. As a base from which to measure, a straight line is used, running from the lowest point of the leading edge to the lowest point of the trailing edge. This line is called the chordal or datum line, $X-X$, in Fig. 28. The dividing lines drawn perpendicular to the datum line are called stations, line No. 5 being called "Station 5," and so on. The distance measured from the datum line to the curve of the upper surface or to the curve of the lower surface on one of the station lines is then called the "ordinate" of the curve at that point.

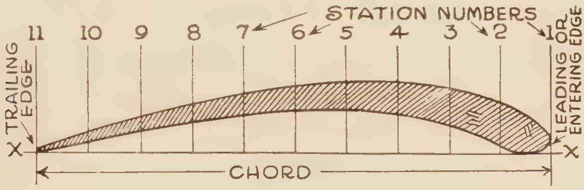


Fig. 28.—How camber is measured.

In this way it is very simple to draw the exact camber of a wing if the ordinate of each station is known. The distance from the chordal line to the upper surface curve is called the upper ordinate, and to the lower surface curve the lower ordinate. The manner in which the camber is designated by a number is to divide the maximum ordinate by the chord. In this way if a wing has a camber of 0.125, it means that the maximum ordinate is five inches and the chord is forty inches. Five divided by forty is 0.125. Another way of designating this particular camber is to say that the maximum ordinate of the wing is 12.5 per cent of the chord, always meaning that of the upper ordinate unless designated otherwise. The greatest camber of the usual modern wing is 0.08, although less camber has been found to be successful.

The shape of the curve from the front to the back of a wing, the camber, has a great deal to do with the action of the wing in response to the air force made to act upon it. A certain shaped camber will make the wing lift or support a greater load in the air than another shape. Other shapes will not lift as much weight but will allow greater speed with just enough lift. Different shapes have been

thoroughly tested and have become more or less standardized. These standard cambers have been given a number and letter, so that when designers or engineers have occasion to refer to them they can do so by number and the particular wing will be known. These wings are such as U. S. A. sections No. 1, 2, 3, 4, etc.; R. A. F. (Royal Aircraft Factories) No. 3, 6; Eiffel Wings No. 35, 36, etc.

Government experiments and later practical tests have produced certain standard shapes for other airplane parts as well as for the wings. Modifications and combinations of these standard shapes then produce the desired result in most all cases of a new design in aircraft.

Slotted Wing.—In the ordinary rigid construction of the wing's leading edge the camber remains the same, no matter what the angle of attack, and tends to send the air currents higher and higher away from the top surface. The burbling shown in 20° illustration, Fig. 19, Chapter III, is greatest when first getting under way at the take-off and when landing, or at any time when the plane has reduced air speed. This amount of burbling has no value as to lift and must be overcome by speed before the wing will lift. The air is deflected upward too much at low speed and allows the plane to settle heavily and too quickly when landing, necessitating a comparatively high speed being maintained until the ship has touched the ground. This results in a "high landing speed." Now, if the camber were made less at low speed, as at the right in Fig. 29, the effective air currents would keep closer to the top surface and supply lift at a lower speed, but this lift would be insufficient at high speed.

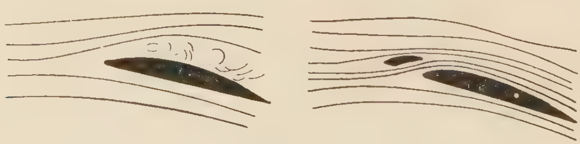


Fig. 29.—Effect of reducing camber at low speed.

A patented feature, perfected by the Handley-Page Co., of England, does just what is desired in this respect—reduces the camber at low speeds. This construction is called the "automatic wing slot" and is illustrated in Fig. 30. A wing using the automatic

slot is made with an auxiliary leading edge running span way of the wing and about as long as an aileron. It is attached to the main wing by a patented suspension which shoves it forward away from the main part of the wing when the wind pressure is reduced below a certain amount. When the auxiliary piece moves forward under this condition, it opens a slot through which the air passes over the main wing at a reduced camber, closer to the top surface. This brings the effective lift into action and suspends the ship in the

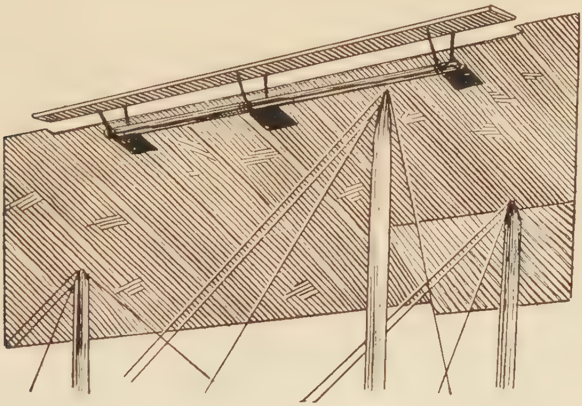


Fig. 30.—Slotted wing application.

air at a slower speed. In taking off the opposite takes place. The slot is open, the air acts on the surface at a slower speed, lifts the machine sooner, and as the speed increases, the increasing pressure presses the auxiliary piece back into place against the main wing, increases the flying lift. The opening and closing of this slot is absolutely automatic and not mechanically accomplished by the pilot.

Wing Covering.—The wing frame is covered with a fabric of best grade unbleached Irish linen, or some other such fabric, that has a tensile strength of at least seventy-five pounds per inch of width in any direction. The material weight is usually from three and three-fourths to four and one-half ounces per square yard. It must be free from filling matter, be wet spun and uncalendered.

The wider it is the more easily it is applied. The fabric is invariably joined with a figure-eight stitching, the stitches coming over ribs when run parallel, although stitches running obliquely are considered best for strength. One way of covering the wings with the fabric is to sew it up in the form of a bag to fit the frame tightly and then slip it over. Another way is to place the wing on supports with the concave side up. The fabric is then fastened

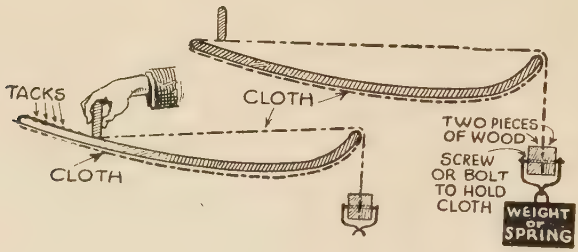


Fig. 31.—Method of applying fabric.

temporarily to the trailing edge, brought under the wing to the leading edge and then over the concave side back to the trailing edge. The fabric is cut large enough so that the material will overlap at all points on the wing and allow for trimming after attaching. An excess amount of material will hang down over the trailing edge and to this is attached a weight that tends to pull the fabric taut over the wing's lower surface. A narrow board is next laid on top of the fabric near the leading edge with the board on edge. Starting at the leading edge and pressing the board down as it is drawn toward the trailing edge, the fabric is pressed down onto the concave side of the ribs and tacked. After the fabric is fastened to the concave side of the ribs the wing is turned over and the fabric is fastened to the convex side of the ribs. A strip of doped tape is placed between the tacks and fabric to prevent tearing. Brass tacks are the only permissible kind to use, as iron or steel will rust and eventually rot both fabric and wood. A better way, and one used by many makers, is to stitch the fabric to bands of thread or tape previously wrapped around the ribs about four inches apart.

After the fabric is stretched over the frame it is then painted with a chemical preparation called "dope." The purpose of the dope is to make the fabric air and moisture proof. It also acts on the fabric in such a way as to shrink it and produce a drum-tight, smooth surface that offers the minimum amount of friction with the passing air.

The fabric should not be applied to the frame too tightly because the dope shrinks it and, if put on too tight, will pull the whole frame out of line and cause damage.

Dope.—Dope in nearly every case is based on cellulose—cellulose acetate or nitrate being most common. This type of base seems to blend in with the cellulose of the fabric in a more satisfactory way than bases of resin, copal, gum or oil such as are used in varnish. Airplane wing dope must be elastic, as there is a certain amount of weaving of the wing, and for this reason shellac or other hard resins are not used.

The dissolving chemicals, called solvents, vary with the make of dope. Some manufacturers use secret compounds best suited to the base that they use. Ether and alcohol were the original solvents, but later others such as acetone, methyl acetone, and methyl acetate were found to be better suited to cellulose acetate. Amyl acetate, ethyl acetate and butyl acetate were found to be very good solvents for nitrate bases.

A fabric-covered frame not doped would become slack and taut with atmospheric changes and would deteriorate due to the elements acting upon it and would provide no protection to the interior wing structure. Sunlight is the enemy of any material, so color pigments are added to the clear dope which successfully shut out the sun's rays from all parts except the wing surface.

Heretofore several coats of clear dope and then an additional several coats of color dope were necessary. The present dopes, however, are made in such a way that the same results are obtained with an application of four coats of pigmented dope. This is, of course, a saving in manufacture. The first two coats of dope are applied by brush, rubbed in until the fabric is well soaked, and as soon as possible after the fabric is placed over the frame. If left too long before doping, the fabric will assume a permanent set, losing its tautness and will not produce a good finish. The other

coats can be applied with an air gun. Before applying the dope, the fabric surface must be perfectly free from any dirt or oil spots. If not, the dope will blister and peel at these spots. Ordinary paint, even automobile lacquers, are not satisfactory finishing coats unless mixed with flexible softening compounds. Dope takes from thirty to forty minutes to dry and at least thirty minutes should be allowed between applications of the different coats.

FUSELAGE CONSTRUCTION

The main structural parts of the fuselage are the frame members running lengthwise and called longerons. The pieces holding the longerons apart, up and down, are called the vertical struts and those holding them apart crosswise, the horizontal struts.

In the old-style plane the fuselage structure was framed with wood and trussed with wire. Modern construction is of duralumin tubing and beams, the manufacture of the wooden frame fuselage being practically discontinued. Duralumin provides a much more rigid construction, less apt to get out of alignment, and provides much more protection in case of accident. This has been demonstrated to the public in aërial motion pictures in which stunt flyers have deliberately cracked up their ships, causing damage only to the wooden-framed wings and none to themselves.

The exact shape of a fuselage varies with the type of airplane and engine, but all of them taper at the rear into a knife edge, the general shape being as streamlined as possible.

The front end of a fuselage is where the greatest variation in construction takes place, because, with very few exceptions, present-day planes are of the tractor type, and the front of the fuselage must be designed to house, or to allow attachment of, the various engine types. With cylinder-in-line engines greater length is provided with a suitable engine bed. Radial engines are bolted to a plate on the front end of the fuselage and require less over-all length. The space in radial engined planes usually occupied by the cylinder-in-line engine is then utilized for fuel tanks that provide additional cruising radius.

The fuel tanks are usually placed directly behind the engine but insulated from it by a metal fire wall, the fuel tanks in turn

being insulated from the remainder of the fuselage by another fire wall protecting passengers or cargo.

The length of a fuselage is necessary to provide sufficient leverage for turning the wings while in flight through the action of the tail control surfaces. The extreme rear end terminates in a stern post which provides an anchor for the rudder, elevators and stabilizers.

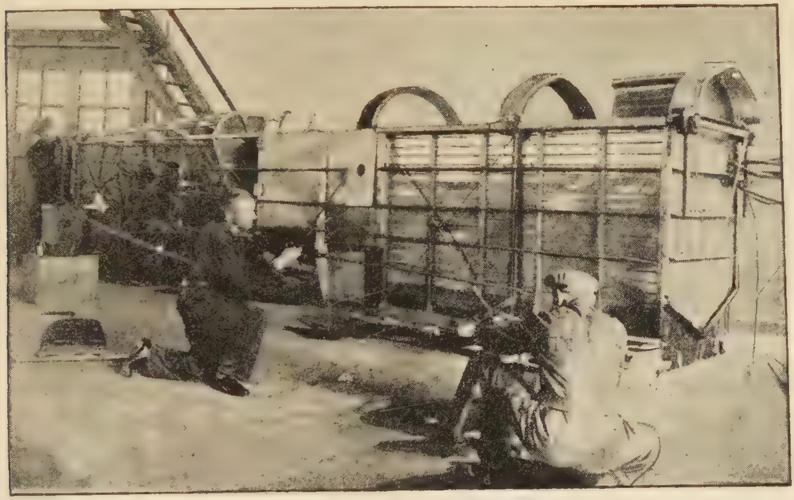


Fig. 32.—Metal frame fuselage construction.

The framework of hollow duralumin tubing is welded together after being trussed and braced with like material and wire. The greatest strength is centered in the front part where the engine is supported, where the load is carried and where the wings exert the greatest lifting strain.

LANDING GEAR

The landing gear is comprised of the wheels and necessary bracing to the fuselage. The landing gear, also called the running gear, is generally considered as part of the fuselage. Old landing-gear design consisted of an axle running directly across from wheel

to wheel and having shock-absorbing rubber rope so attached as to provide a cushioning effect while running over rough ground. The axle traveled up and down in guides attached to the bracing struts and the rubber rope tended to hold the axle at the bottom of these guides.

The straight axle, however, provided a decided disadvantage when it became necessary to land in any tall growth. The high grass or grain would wrap around the axle with a decided retarding effect and cause the whole plane to act on it with a pivot effect, nose over and cause considerable damage. This defect lead to the invention of the Vee-strut landing gear, illustrated in Fig. 1, Chapter II, which presents no obstruction to high growth. The old-style rubber rope shock absorbers are still used on some ships for the sake of economy but are gradually giving way to hydraulic and air springs. On biplanes the landing gear struts are attached to the lower longerons, but on some monoplanes other struts also lead to the wings.

The wheels are invariably wire-spoked, stream lined with fabric and pneumatic tired. Wheel brakes are provided, each wheel being operated independently or together, as the pilot desires. This is a great help in turning on the ground by braking the wheel on the side toward which it is desired to turn. Some brake controls are operated by a pedal arrangement on the rudder bar, while others have a separate lever similar to a control stick. Moving the lever sideways operates the one brake on that side, while moving it backward applies both brakes together.

The first brakes used on airplane wheels were not much of a success. They stopped the wheels all right, too well in fact, and then with the wheels acting as a pivot, the rest of the machine would continue to go on, nose over on its back and be damaged. To overcome this fault the landing wheels are now placed farther ahead of the center of gravity. It is still possible to nose over, however, if the brakes are applied with too much force before the plane has lost speed.

TAIL SKID

The tail skid is a support which holds the tail end of the fuselage up from dragging on the ground. It is provided with a shock

absorber to protect the plane from undue stresses while taxiing. Old construction provides it with a metal shoe so bent as to dig into the ground and provide somewhat of a braking effect through drag. This practice threw excessive strains on the fuselage structure, however, and was practically abandoned when the advent of brakes eliminated its necessity altogether. Tail skids are now being provided with wheels set in a caster frame so they will track as the tail is swung around.

CHAPTER V

CONTROL AND STABILIZING SURFACES

CONTROLLING the direction of, or steering, an automobile or a boat is a most simple matter in comparison to controlling the direction of an airplane. The automobile is on solid ground, kept from tipping sideways or up and down by the road wheels, one at each corner. The only control necessary is that for direction as accomplished through the steering wheel. A boat is supported by the water and controlled only as to direction by the rudder at the rear. The supporting medium of the airplane, air, is not solid, however, and cannot be relied upon to support and keep it level sideways or up and down. For this reason control must be provided for tipping sideways, up and down and for direction as well. This means that three separate and distinct control mediums are provided: the ailerons for lateral control, the elevators for longitudinal control, and the rudder for directional control.

The control mediums are small movable wing surfaces; ailerons, one near the tip of each wing surface; two elevators, one on each side of the rudder at the tail; and a rudder at the extreme rear end of the fuselage. In the early planes these control surfaces were separate small wing sections independently mounted, the ailerons between the two wings of a biplane, the elevators above or below the rudder. In some constructions the elevators are still mounted above the fuselage in order to take advantage of the propeller slip stream when the engine is mounted above the fuselage, as in the Fokker amphibian of Fig. 2, Chapter II.

It was discovered that if these control surfaces were made a hinged portion of a fixed surface the efficiency was greatly increased. So today the ailerons are a hinged part of the main wings, the elevators a hinged part of the horizontal stabilizers and the rudder a hinged part of the vertical stabilizer.

The internal frame construction of these various control sur-

faces is very similar to that of the wings, only on a smaller scale.

The position of the control surfaces is governed by the pilot through his movement of the control levers in the cockpit. The rudder is controlled by a bar, pivoted in the center on the floor and operated by the feet. The aileron and elevator movement control is combined in one control lever, named the Joyce stick, commonly called the "joy stick." This stick is mounted on a ball joint similar to an automobile gear shift so that the extreme top and the extreme bottom of it are integral, the joint allowing it to be moved from side to side, backward and forward, or in a complete circle. It is connected to the ailerons and elevators through cables or rods.

Moving the stick to the right of its upright position elevates the right aileron, and at the same time depresses the left aileron. The wind acting on the surfaces in this position pushes the right wing down and the left wing up, causing the ship to tip, or bank, toward the right. The movement of the stick to the left of its upright position produces the opposite effect, banking the ship toward the left. In other words, moving the stick left, banks left and moving it to the right, banks right.

In ships having large wing and aileron area the strength necessary to move the stick sideways in order to alter the position of the surfaces against the force of the wind is considerable, so in this case a wheel, similar to an automobile steering wheel, is mounted on top of the stick and the turning of the wheel operates the ailerons. This latter method of aileron control is called the Deperdussin, "Dep" for short, control, after the man who designed it. The area of the ailerons is usually about one-eighth of the total wing area.

The position of the elevators is always controlled by the pushing forward or pulling back of the stick whether of Dep control or straight stick. Pushing forward on the stick from its upright position depresses the elevator surfaces, causing the tail to go up and the nose to point down. This results in the plane diving. Pulling back on the stick produces the opposite effect; the elevator surfaces are pulled up, depressing the tail and raising the nose. This results in the plane climbing.

The cables or rods connecting the stick and the elevators must

be crossed, as shown in Fig. 33, in order to accomplish the desired movement naturally. It would not feel natural to have the plane nose down when the stick was pulled back, nor to climb when the stick was pushed forward.

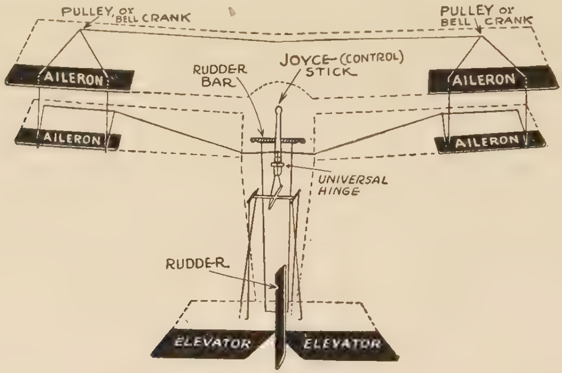


Fig. 33.—Control surfaces, in black, showing method of control hook-up.

The rudder position is governed by its own individual control, the rudder bar. Each side of the rudder bar, on each side of the pivot, is connected to the corresponding side of the rudder surface. Therefore pushing forward on the right side of the rudder bar pulls the rudder into the wind on the right of the fuselage, swings the tail left and the nose to the right. The opposite movement of the rudder bar produces the opposite effect, swinging the nose to the left.

It can be plainly seen that, with no solid support while in the air and constantly being acted upon by changing air currents and wind gusts, the three controls must be in practically constant movement to keep the ship flying level.

Balanced Control Surfaces.—The arm on the control surface, to which the control cable is attached, is called the horn. The placing of this horn and its length has a great deal to do with the amount of force necessary to change the position of the control surface and overcome the resistance of the wind. Did you ever attempt to hold a large surface broadside to a high wind? If you have, you appre-

ciate the strength necessary to do so. This same strength, obtained through leverage, is necessary to place a control surface even partly broadside to the wind as when changing the direction of airplane travel.

In an endeavor to reduce the effort necessary to move the airplane control surfaces, aëronautical engineers developed the idea of balancing them. This consists of making a part of the control surface assist in moving the other part. As said before, each control surface is hinged to another fixed surface. Balancing is accomplished by placing a small percentage, about one-eighth, of the surface ahead of the hinge, as in Fig 34. This illustrates a balanced rudder in which the relative wind striking the area A ahead of the hinge exerts a force tending to move the area B in the opposite direction. This, of course, reduces the amount of effort necessarily exerted by the pilot on the rudder bar. Balancing of other control surfaces is accomplished on the same principle and provides both additional area and reduced effort.

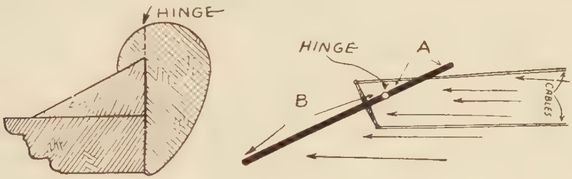


Fig. 34.—A balanced rudder.

Balancing a surface produces considerable force on the hinge, due to the relation the surface now has to the large surface broadside to the wind. Therefore the amount of balance surface cannot be too large or else the whole airfoil is liable to be torn off. Also it is desirable to exert some effort to move the control surfaces in order to have the "feel" of them; therefore just enough balance surface is provided to help out a little. In purely racing, or very high-speed, planes it has been found better to have plain control surfaces, balancing them making them too touchy. On large transport planes the control surface area is very large, requiring great leverage and effort to move them; here the balanced surface proves the best construction.

Stability.—Stability is the power of a body which causes it, when disturbed from its steady motion, to automatically develop forces that try to restore the body to its original steady motion. This, in an airplane, means the inherent ability to continue on a level line of flight, or to return to a level line of flight after having been disturbed from this state. The disturbing forces are gusts of wind striking the plane under one wing, under the tail or broadside. These disturbances are continually acting on a plane and from all directions. Their force is somewhat overcome by the use of surfaces called stabilizers.

The keel of a boat acts as a directional stabilizer in that it tends to prevent the boat from veering off a straight course. An airfoil is placed directly ahead of the airplane rudder and parallel with it and acts in a similar capacity as the boat's keel. This surface is called the vertical stabilizer and the rudder is attached to its trailing edge. The vertical stabilizer is sometimes called the "fin."

In order to provide longitudinal stability horizontal stabilizer surfaces are attached directly to the tail of the fuselage, and to their trailing edges are hinged the elevators, sometimes called the "flippers." The complete tail assembly, including control and stabilizer surfaces together with their bracing, is referred to as the "empennage."

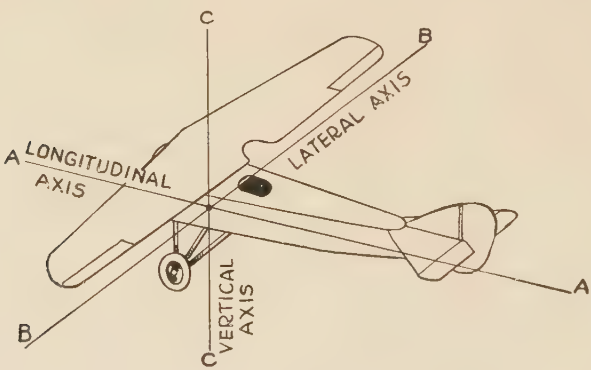


Fig. 35.—Axis of airplane rotation.

The airplane has three axes of rotation, as illustrated in Fig. 35. There is the longitudinal axis, *A–A*, around which the plane

rotates when banking; the lateral axis, *B–B*, around which the plane rotates when it climbs or dives; and the vertical axis, *C–C*, around which the plane rotates when changing direction around the horizon. The air is invariably in motion, mostly commotion, similar to the waves and cross currents of large bodies of water. This motion of the air is very often in a more violent form, corresponding to geysers and cataracts. These disturbances attempt to turn the plane about its various axes against the wishes of the pilot. These unstable motions are called *yawing*, around the vertical axis; *rolling*, around the longitudinal axis; and *pitching*, around the lateral axis. The purpose of the stabilizers is to oppose these unstable motions as much as possible and return the plane to level flight.

There are a great many other things necessary to produce a stable ship besides stabilizing surfaces, among them the angles of the wing surfaces in relation to each other, the distribution of the weight in relation to the center of gravity and the shape of the fuselage.

First, let us look into the placing and the angle of the surfaces. Besides providing leverage, there is another reason for the comparatively long fuselage. As the wings rush through the air they create a considerable disturbance. The chaotic condition of the air so disturbed might be called turbulence. If the empennage were close to the wings, the turbulence would greatly affect their proper functioning. When the empennage is placed farther back the air has at least begun to straighten out and the downwash from the wings has lost a great deal of its disturbing effect.

On the majority of airplanes the fuselage is rectangular in shape with flat surfaces. This presents a certain keel effect in that, if the ship yawed, or skidded, the wind striking the flat side of the fuselage would tend to straighten it out again in the air stream. This adds considerably to the stability. A round fuselage, of course, presents no great amount of keel surface.

Gap and Stagger.—As a wing splits the air a great amount is deflected upward, and some downward. In biplane construction this fact would cause considerable confliction, called choking, of the air between the wings if they were not placed sufficiently far apart. The distance so separating wing surfaces is called the *gap*. In order not to require too great a gap to eliminate the air choking,

the leading edge of the upper wing is placed somewhat ahead of the leading edge of the lower wing. This allows the uprushing wind from the lower wing to miss the trailing edge of the upper wing. The distance which one leading edge is ahead of the other leading edge of wings so placed is called the *stagger*. Very rarely you will see ships with back stagger, the upper wing a little back of the lower wing.

Decalage.—For stabilizing reasons, as well as lifting efficiency, the upper and lower wings and the horizontal stabilizers may all be set with different angles of incidence. The difference in the angles of incidence is called *decalage*.

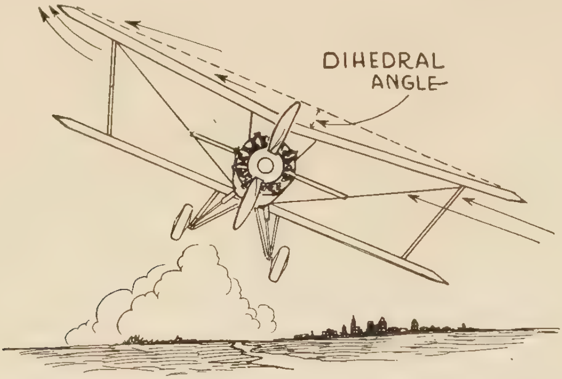


Fig. 36.—Dihedral angle applied to wings to overcome rolling.

Dihedral.—One of the most unstable actions of an airplane is that of tipping sideways, causing a side-slip toward the ground, when an ascending current of air strikes it under one wing. To overcome this tendency the wings are sometimes tipped up, or given a dihedral angle, as in Fig. 36. As the machine attempts to side-slip, the air acts on the wings in the direction of the arrows, pushing the low wing up and the high wing down.

Another theory is that the low wing presents more lifting area to the relative wind and consequently more lifting force is being exerted on it than on the high wing. A certain amount of effective wind is also supposed to slip out by the high wing tip, called end

leakage, and further reduce the lift here. This results in the low wing rising until the lift on the two wings is again equal and the ship is on an even keel. It is a known fact that dihedral does make a more stable ship.

Center of Gravity and Center of Lift.—Another factor that has a direct bearing on the stability of an airplane is the balancing relative to weight. The point in a plane where, if a single support were placed the machine would be exactly balanced, is called the center of gravity. The spot on a plane where, if a rope were attached and the machine suspended in the air by it, it would hang exactly balanced, is called the center of lift. The center of lift in actual flight moves with the center of pressure, as explained before.

If a ship were flying in perfectly still air it would have absolute stability were the wings so placed that the center of pressure came directly over the center of gravity. But for certain reasons this is not done. An airplane requires air speed to produce lift and also for the control surfaces to act. If the engine stops in midair we want the ship to dive in order to maintain flying speed. So the center of gravity (C.G.) is made to be just ahead of the center of pressure (C.P.). Then if the engine stops, the added weight of the nose causes the plane to dive, gain air speed and be under control.

Wash-In (-Out) Torque.—Torque is the tendency of a revolving part to revolve its support in the opposite direction. The torque of an airplane engine is sometimes a troublesome factor, because if the engine is revolving clockwise it tends to revolve the whole plane in the air anti-clockwise. This is caused by the inertia and air resistance of the propeller. This, of course, produces instability and is counteracted by increasing the angle of incidence at one wing tip, or reducing it at the other. Increasing the angle of incidence supplies more lift to the wing being forced down and overcomes the torque. When a wing tip has increased incidence it is said to have *wash-in*, and when the incidence is reduced the wing is said to have *wash-out*.

Sweepback.—In order to overcome directional instability, or the tendency to yaw, the wings are sometimes given sweepback in addition to the vertical stabilizer. Sweepback is illustrated in Fig. 37, and means that the wing tips are back of the center section leading

edge. The result of this is that, when the plane is yawed right, the left wing is swung forward, presents more drag to the wind and in consequence is forced back again until counterbalanced by the drag of the right wing.

Sweepback is very seldom used for directional stability, however. It is better suited for locating the center of gravity in relation to the center of lift. For instance, suppose that it is necessary to locate the wings forward of the center of gravity in order that the pilot may have better visibility, or for other reasons. It is still necessary to place the center of pressure properly in relation to the center of gravity and this is done by giving the wings sweepback and the consequent moving back of the center of pressure, *A–A*.

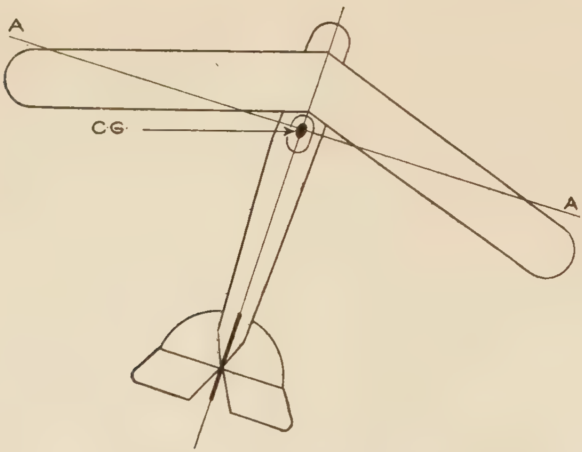


Fig. 37.—Sweepback of wings.

Over-Stability.—A plane should not be too stable, necessitating abnormal control surfaces and force to move them when it is desired to change the attitude of the plane. For instance, if you wanted to bank, too great lateral stability would resist your efforts and tend to keep the ship on a level keel. This condition results in what we call a stiff plane. This over-stability is fine for ships intended only for straight flying or long flights, as it then requires very little effort to maintain an even keel. On the other hand, sta-

bility is sacrificed in planes required to maneuver quickly in order to make the controls touchy and the ship quick to respond.

Controllability and Maneuverability.—Besides stability a very desirable quality is ease of maneuvering and ease of control. The two terms are often confused when referring to an airplane. A plane might be easy to maneuver but difficult to control, and conversely easy to control but difficult to maneuver.

Maneuverability is the ability of an airplane to change its position in the air in the least possible time, as when making an almost instantaneous reversal of the direction of travel.

On the other hand, controllability does not necessarily mean maneuverability. A large transport plane weighing many tons may require very little effort to control it, but still be unable to loop, tail spin, or do many other acrobatics that a smaller plane with maneuverability could do. For this reason controllability means the ability of the pilot to govern the actions of an airplane in the air with the least exertion of physical force.

CHAPTER VI

PRINCIPLE AND OPERATION OF THE GASOLINE ENGINE

THIS chapter is intended only for those who do not understand the principle on which a four-stroke cycle internal combustion gasoline engine operates.

Gasoline is the fuel used in this type of engine, but it is not explosive unless mixed with air and compressed before being ignited. It will blaze if ignited but will not explode.

The explosion of the gasoline vapor imparts the force and power to the engine. An explosion is nothing more than the very rapid burning of the explosive mixture. The more rapid the burning, the more force in the explosion. Oxygen, if mixed with certain other elements, becomes highly explosive. Air contains oxygen, therefore, when liquid gasoline is made into a vapor, or gas, by being mixed with air, the resulting mixture burns very easily and rapidly. If the vapor gas mixture is compressed before burning, it burns that much more rapidly, or with greater explosive force. When gas explodes the resulting heat expands the air with great speed, producing the force that runs the engine.

In order to harness and use this force the mixture of gasoline and air is placed in a small space which is the cylinder of the engine. This cylinder is a round tube, the diameter depending upon the engine, closed at one end and open at the other, as illustrated in Fig. 38.

Into the lower part of the cylinder is placed a piston, fitting tight enough to prevent the gas mixture above it escaping, but still loose enough to allow the piston to slide freely up and down in the cylinder.

At the moment that the explosive mixture above the piston is ignited, the piston is at its farthest up point of travel, and the resulting explosive force drives it down toward the open end of the cylinder. The piston is connected to a shaft called the crankshaft,

placed at right angles to the piston and connected to the piston by a stout metal link, called a connecting rod, and the downward motion of the piston turns the crankshaft to which is attached the propeller.

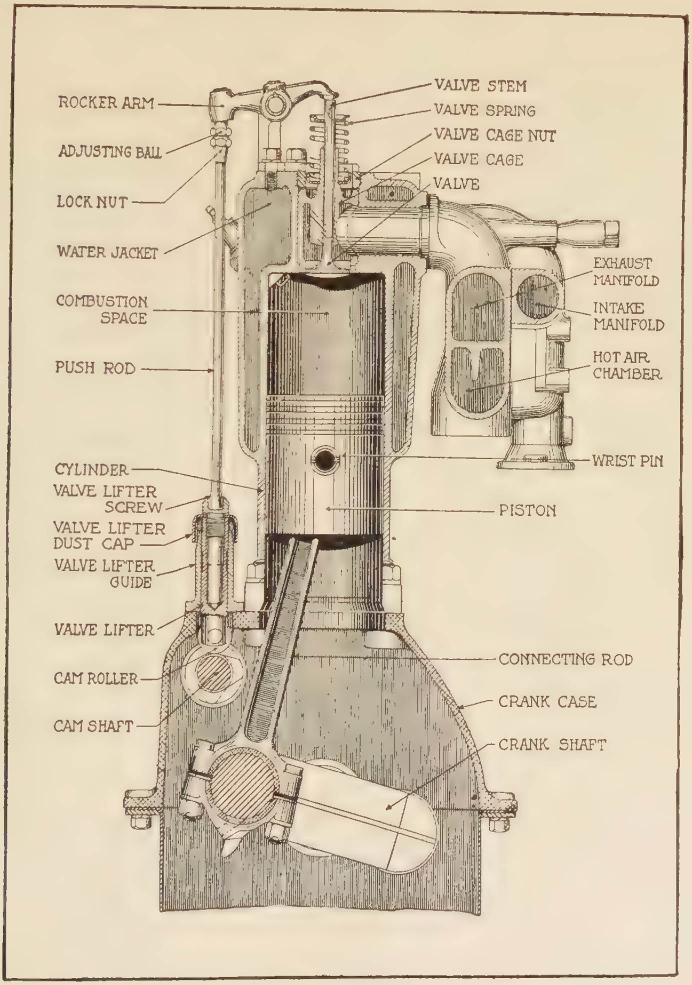


Fig. 38.—The parts of a cylinder in a gasoline engine.

Attached to the engine and connected to the space in the cylinder above the piston by a pipe is a device called a carburetor. The function of the carburetor is to change the liquid gasoline into a vapor, then mix the gasoline vapor with just the right amount of air to form an explosive mixture.

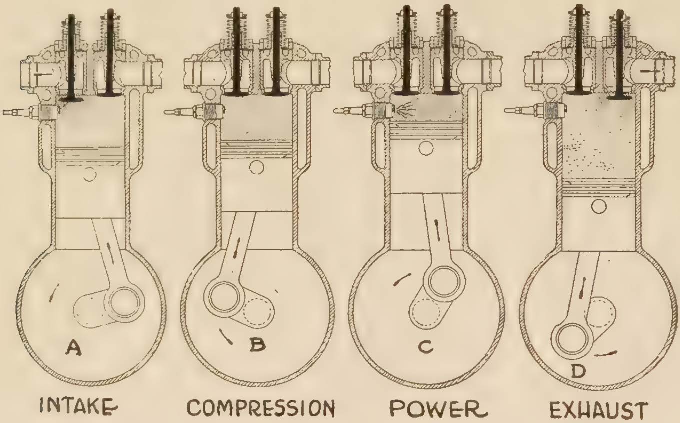


Fig. 39.—The four strokes of a piston.

After the explosive mixture has reached the space in the cylinder above the piston, called the combustion chamber, or space, it is set on fire by an electric spark. The spark is caused to jump between two metal points placed in the combustion chamber. In jumping through the explosive mixture the spark ignites it, the gas expands and drives the piston down toward the open end of the cylinder. If there was nothing to prevent it, the piston, under these circumstances, would be forced completely out of the open end of the cylinder. But to prevent this there is a steel pin, called a wrist pin, placed through the walls of the piston and reaching from one side to the other. One end of the connecting rod is attached to this pin and the other end is attached to the crankshaft with a bearing at each of the two points. The point on the crankshaft at which the connecting rod is attached is offset and forms a crank on the shaft, hence the name, crankshaft. This construction allows the downward and following upward motion of the piston being con-

verted to a rotary motion of the crankshaft, the action being illustrated in Fig. 39.

It can be seen that inasmuch as the explosion occurs in the space above the piston, the piston receives power from the burning gas only on its top. Therefore a gasoline engine delivers power only while the piston is traveling downward after an explosion in the combustion chamber.

On automobile engines a heavy wheel, called a flywheel, is attached to the rear end of the crankshaft in order to force the piston back up into the cylinder so that another power stroke may take place. As the piston causes the crankshaft to turn, it revolves the flywheel which gains momentum enough to keep the crankshaft revolving and, through the connecting rod, returns the piston up into the cylinder.

On airplane engines the function of the flywheel is carried out by the propeller. Without either flywheel or propeller the engine would stop as soon as the piston had traveled as far down in the cylinder as it would go because there would be no force to move it back again.

Constant friction results in wear, and after a gasoline engine had been run for a long time, both the piston and the cylinder would wear to such an extent that they would no longer make a gas-tight fit. Gas must be compressed in order to explode, and if the compression escaped between the piston and the cylinder walls, the engine would not deliver its full power.

To overcome wear to a certain extent and prevent such compression leakage, grooves are cut around the outside of the piston wall and a metal ring, fitting snugly at all points, is placed in each groove. The ring is cut completely through at one point so that it can be opened enough to slip over the piston and drop into the groove. The ring is made of elastic metal, and when it is in the groove, tends to spread out. When the piston, having the rings in place, is inserted in the cylinder, the rings press out against the cylinder wall, providing a gas-tight fit. Several grooves are provided, each with its ring, so that if compression escapes past one it is stopped by the next. These rings wear in course of time and lose their elasticity but can be replaced with new ones.

As stated before, one end of the cylinder is closed, but it is

necessary to provide some means of entry for the gas to reach the combustion chamber and also an exit for the burned gas after it has lost its usefulness. The gases enter and leave the cylinder through holes whose passages are opened and closed periodically by discs called valves.

A steel rod is fastened to the valve in its exact center, and this rod is called the valve stem. A spring is attached to the valve stem in such a manner that it tends to keep the valve on its seat, thereby closing off the entrance and exit holes and making the cylinder combustion chamber compression tight.

When gas is to pass into or out of the cylinder the valve stem is pushed on mechanically, forcing the valve away from the hole and opening the passage. There are usually two valves to a cylinder; one opens to let fresh gas in, called the inlet, or intake, valve; the other opens to let the burned gases out, called the exhaust valve.

Now let's see how all these things work together to produce power. When the piston has traveled from either end of the cylinder to the other end it has completed what is called one stroke. Therefore when the piston travels from the top of the cylinder to the bottom of the cylinder it has completed one stroke; when it travels from the bottom of the cylinder to the top of the cylinder it has completed another stroke. Now, looking at Fig. 39, notice that while the crankshaft makes one revolution the piston has had to move down and then up, making two strokes. In one-cylinder four-stroke cycle engines the piston must make four strokes and the crankshaft two revolutions for each explosive power impulse.

In order to operate, the combustion space must be full of gas, so assuming that the piston is at its farthest point from the crankshaft, the inlet valve is open. As the crankshaft turns it draws the piston down, creates a suction that draws a gas mixture from the carburetor through the pipe and inlet valve into the combustion chamber, as illustrated at *A* in Fig. 39. This downward stroke of drawing in fresh gas is called the intake, or inlet, stroke.

When the piston has reached its farthest down point of travel no more gas can be sucked in, so the inlet valve closes, trapping the gas because the other valve is also closed. The crankshaft continues to revolve and forces the piston back toward the top of the

cylinder and compresses the gas trapped there. This movement of the piston is called the compression stroke.

When the piston has next reached its farthest up point of travel, the ignition spark occurs, setting fire to the gas, and the explosive force sends the piston down toward the bottom of the cylinder again. This movement is called the power stroke.

When the piston has reached its farthest down point of travel on the power stroke, the gas is of no further use, it is burned out, so it is gotten rid of by opening the exhaust valve as the piston reaches the downward extent of travel. As the crankshaft continues to revolve it forces the piston up again toward the top of the cylinder and, the exhaust valve being open, the burned gas is forced out through the exhaust passage. This last movement is called the exhaust stroke.

This last movement has completed the four strokes with two revolutions of the crankshaft and the operations start all over again with the intake stroke as long as the engine continues to run. In order to stop the engine the electrical circuit supplying the spark is broken.

The mechanical means of raising the valves from their seats in the combustion chamber utilizes cams and push rods. A cam is a piece of steel that is higher on one side than on the other. It takes a separate cam to operate each valve and they are placed on a shaft in exactly the right position so as to cause the valves to open and close at just the right instant. As said before, the crankshaft makes two complete revolutions for each explosion, so the valves are not opened each revolution but are opened every other revolution. Therefore the cams must turn around just half as many times as does the crankshaft. This is accomplished by gearing the shaft with the cams, called the camshaft, to the crankshaft. In order to make the camshaft revolve just half as often as the crankshaft, the gear on the camshaft is twice as large and has twice as many teeth as the one on the crankshaft.

As the high part of the cam, called the lobe, comes around it pushes up on a piece of steel called the valve tappet, Fig. 38, which in turn pushes up on another piece of steel called a push rod. The push rod pushes on up on one end of a rocker arm which is hinged in its center. Pushing up on one end of the

rocker arm forces down the other end which rests on the valve stem. This motion pushes the valve off its seat and opens the valve. This is the action of overhead valve operation, which is the type generally used in aëronautical engines. The purpose of the valve tappet is to relieve the push rod of any side strain that would occur if the cam lobe were to strike the push rod itself as it came around. The valve tappet slides up and down in a hardened steel casing, called the valve tappet guide. The guide is fastened very rigidly to the engine and is so hard that it wears very slowly.

There is a slight space between the valve stem and the rocker arm to insure the valve closing firmly on its seat. As the parts wear or the valve head is pounded down into its seat this clearance will vary. In order to compensate for this varying clearance, an adjustment is provided on the valve tappet or push rod to make it longer or shorter. This adjustment is sometimes in the form of a screw threaded into the tappet. Unscrewing the adjustment will make the tappet longer and reduce the clearance; screwing in will shorten the tappet, making the clearance greater.

In order to supply power evenly, several cylinders are made to operate in conjunction with each other, resulting in four, six, eight, nine, ten, twelve and even twenty-four cylinder engines. These types will be explained later.

CHAPTER VII

AVIATION ENGINE CHARACTERISTICS

THE airplane engine is the part that receives the most punishment of all, but in spite of the extreme demands made upon it—absolute reliability, lightness, fuel economy, and compactness—it has developed into the highest type of internal combustion motor so far produced.

Do not think that the aëronautical engine is a small edition of an automobile engine, although the Packard Motor Car Co., Continental and Lycoming are manufacturers not exclusively aëronautical, who have been successful in producing engines suitable for use in aviation.

About the only relation an aviation engine bears to the automobile engine is that both operate on the principle of producing power from compressed explosive gas, ignited by an electric spark. Many refinements have been added to the aëronautical engine and the whole much more delicately constructed.

The abuse and punishment that the materials in an aëronautical engine receive are terrific. For instance, both the size and weight of all parts are reduced to the absolute minimum, then they are run at almost top speed for hours at a time, called upon to deliver very seldom less than ninety per cent of their rated ability and more often the whole one hundred per cent. On top of this the airplane engine has a yielding, flimsy foundation, compared to that of the automobile engine. Then it is expected to function perfectly under the varying conditions of temperature and air density encountered with altitude.

The weight of the average airplane motor, less oil and water, is from two to three pounds per horsepower developed. One twenty-four cylinder engine weighs only eighteen ounces per horsepower. This exceptionally light power plant is called upon to pull a load of from fifteen to twenty-five pounds per horsepower.

Compare these engines with an automobile engine which usually weighs two to three times as much per horsepower, is more heavily constructed throughout, has a solid cushioned support and is very seldom called upon to develop more than forty per cent of its rated ability.

Most people imagine that the maintenance of an airplane engine is expensive, that they must be overhauled frequently and that they literally eat up gasoline. The modern flying motor does not need an overhaul under two hundred hours of operation. At an average of one hundred miles an hour this means 20,000 miles. What automobile engine does not need an overhauling at the end of 20,000 miles? The average fuel consumption of the aviation engine is from twelve to fifteen miles per gallon and some average twenty to twenty-five miles. This compares very favorably with the automobile engine fuel consumption.

Weight is reduced in every conceivable manner and the process sometimes increases the strength of the part. This is especially true in the tubular steel connecting rods and hollow crankshaft. Weight for weight, tubular steel is much stronger than the solid bar construction. Metal alloys, mostly of the aluminum variety, are used extensively, but where stronger metal is absolutely necessary, it is "routed" out, hollowed, grooved or cut down in any manner possible consistent with the desired strength.

On some engines the cylinders are machined from solid steel forgings or drawn tubes and the walls cut down to less than five sixty-fourths of an inch thick. The water jackets are usually made as a separate piece of aluminum alloy, sometimes duralumin. The most common practice is a block casting water jacket of aluminum alloy machined to take a wearing liner or cylinder surface of thin steel pressed into the water jacket bore.

Pistons are of aluminum alloy for both lightness and heat radiating qualities. The crankcase allows a great amount of weight economy by being made entirely of aluminum.

On the cylinder-in-line type of engine the cylinders are arranged in "banks" of four or six cylinders, depending upon the total number of cylinders in the engine. Their power is transmitted to one common crankshaft. The cylinder water jackets are sometimes cast in one block, thereby binding the separate cylinders together in one

rigid assembly. Other types of construction assemble the water jackets to their respective cylinders separately and then bind them together by the camshaft housing running across the top of the cylinder heads.

In single-bank engines, having all of the cylinders in line, one behind the other, the conventional connecting rod and bearing is used, but when the cylinders are arranged in a V shape, it necessitates a different bearing arrangement because two or more rods are operating on one crank throw. There are three types of construction under the latter circumstances: the clevis, or forked, type, the articulated type, and side-by-side type.

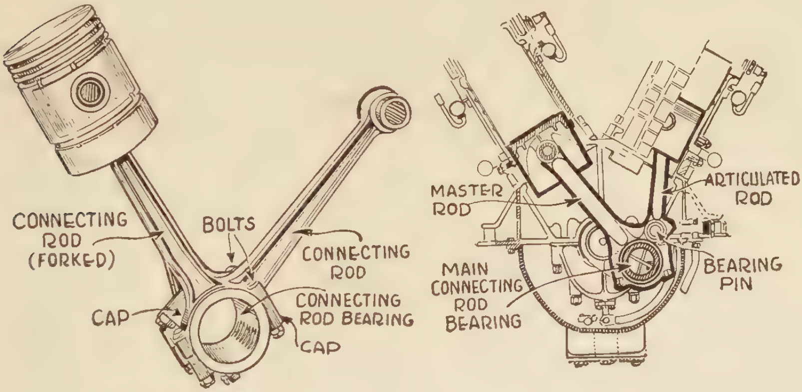


Fig. 40.—Clevis and articulated connecting rod design.

Clevis Rod.—In the clevis construction one rod big end is included between the two forks or jaws of the opposing rod big end, Fig. 40. Old practice was to stagger opposing cylinders, one slightly behind the other, and place the rod bearings side by side on the crank throw. This staggering is illustrated in the Curtiss OX5 engine of Fig. 41. The clevis type permits a much shorter crankshaft and crankcase, thereby greatly reducing the total weight.

Articulated Rod.—In the articulated type of construction one rod is integral with the bearing attached to the crankshaft throw and called the main or master rod. The other rods are called the link rods and their lower end is attached to the outside of the master

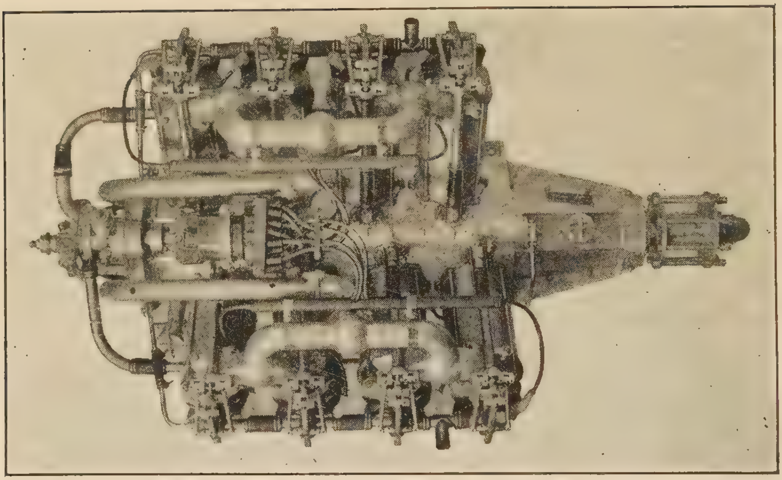


Fig. 41.—Curtiss OX5 engine showing staggered cylinders.

connecting rod bearing case by a pin and bushing. The articulated system is used on the Curtiss D-12s and Packard engines as well as on most other V type aviation motors.

Main Bearings.—A main bearing of high-grade babbitt, or Fahrig metal, with a bronze shell backing is usually placed between each two crank throws of the cylinder-in-line engines to prevent crankshaft deflection, or whip, and thereby to reduce vibration.

The thrust bearing, invariably of the ball type, is required to withstand a constant load and is therefore of the highest type and material. Its detail construction varies according to whether the engine is the pusher or tractor type. A bearing made for one type must be changed before operating the engine as the opposite type. However, the whole engine is usually constructed to operate as one or the other and cannot be operated except as originally designed.

Balance.—All possible vibration is eliminated by balancing both reciprocating and rotating parts. Vibration, if allowed to go unchecked, will eventually crystallize fittings and other important metal fastenings besides loosening the structural framework of the whole plane. Vibration, with its continual hum and tremor, will soon tire the pilot also.

A propeller with one blade heavier than the other or with obstructions in the propeller stream will cause excessive vibration. Faulty carburetor mixture, poor compression in one or two cylinders, poor valve clearance adjustment, or faulty spark plugs will cause a very great vibration. Structural parts of the plane placed too close to the propeller will cause a periodic cushioning of the propeller slip stream, resulting in vibration.

"Static" balance is considered enough for stationary or marine engines but not for aëronautical engines. The latter must also be in "dynamic" balance.

If a crankshaft is placed on knife edges, a heavy spot on a crankpin or other part will cause it to roll on the knife edges until the heavy portion falls downward. If the heavy portion is then drilled out to remove the excess weight, so that the shaft will rest on the knife edges with no tendency to roll in either direction, it is then in static balance. It does not necessarily follow, though, that it is in dynamic balance; there may be an unequal distribution of weight over the length of the shaft, in other words, the rear end may be heavier than the front end. When this inaccuracy is overcome the shaft is also in dynamic balance.

All revolving parts should be in perfect static balance and every shaft should be in dynamic balance. Every reciprocating part, such as pistons, connecting rods, valves and piston pins, should be of equal weight with like parts. If they are not, the oscillating jerky movement communicated to the whole machine soon loosens it up.

For smoothness of operation and for the greatest efficiency, power should be applied to the propeller continuously and not in a series of distinct jerks. To obtain this requires an engine with a sufficient number of cylinders to insure overlapping of the power impulses.

When an engine is of six or more cylinders one cylinder will commence its power stroke before the preceding cylinder fired has finished its power stroke. In this way the power impulses overlap and a certain degree of continuous power is obtained. The only drawback is the limit on the number of cylinders possible without the engine becoming hopelessly complicated. So far, twenty-four cylinders have been found to deliver a practically continuous power flow, but eight and twelve cylinders are the most popular of

the cylinder-in-line type and nine cylinders in the radial type.

The airplane motor is most generally operated by men either inexperienced or careless in handling such delicate machinery. The average pilot's temperament is not mechanically sympathetic. He does not spare the motor abuse, but rather delights in the opposite. For this reason simplicity is one of the most desirable qualities—the fewer parts the less they are liable to go wrong.

Another desirable engine quality is accessibility. It is too easy to postpone attention to oil strainers, carburetor, spark plugs and ignition system when they are difficult to get at.

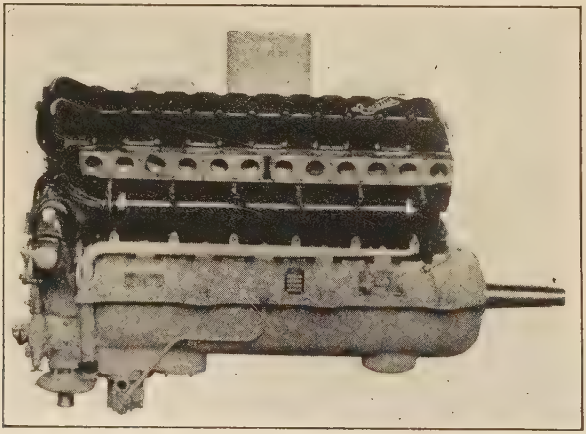


Fig. 42—Curtiss D-12, 435 h.p. engine.

The radial engine, of which the Wright "Whirlwind" is one of the most popular, has proved very efficient due to its allowing easy maneuver of the plane, much less weight per horsepower delivered and absence of water cooling accessories. All cylinder-in-line engines are water cooled and most radials are air cooled. There are advantages and disadvantages in both cooling methods. Cylinder-in-line engines are narrower, presenting less resistance to the wind but have added weight due to water, radiator and piping. Radials do not have the water, radiator and piping weight, but are broader and present more wind resistance. This radial resistance is some-

what overcome by streamline cowling that splits and directs the cooling air away from flat surfaces and to the circular cylinders.

Water cooling of the cylinder-in-line engines is necessary because of the inability to properly cool any but the front cylinder by air due to the shielding of those behind. In the radial engine all cylinders are exposed to the wind. A long cylinder-in-line engine increases the length of the fuselage and adds weight. The inertia of a long motor hinders straightening out quickly after a dive, or a quick change of direction. Water cooling, however, permits a higher compression with a consequent greater horsepower output per cylinder. This added horsepower may be used up in carrying the added weight of the cooling system and its temperature control device.

When using water for cooling, the location of the radiator varies. It is sometimes placed in front of the engine as in automobile construction; at other times it is either over or under the engine and occasionally it is alongside of the fuselage. The location is generally the manufacturer's choice and reflects his idea of the greatest all-around efficiency.

Lubrication.—Perfect and complete lubrication is the greatest factor in providing uninterrupted operation of the aviation motor. High speed, constant bearing load and high oil temperature make it imperative that the oiling system function every minute. As a matter of fact, a minute is a long time for an engine operating under these conditions to run without oil unless ruination results.

Characteristics of the oiling system are high pressure to all bearings and the use of a dry sump. A dry sump means that when the oil has been thrown out of the bearings after use it collects in a recess, called the sump, from where it is pumped by a suction, or scavenging, pump and returned to the oil reservoir. After being sucked from the sump and before it reaches the reservoir, the oil is cooled by being passed through an oil radiator or by some other means.

The splash system of oiling, common to some automobiles, is not possible to use because of the high crankcase temperature and various steep angles of climb and dive at which the airplane engine is operated.

Castor oil, due to its high viscosity and ability to withstand heat,

is the most efficient and commonly used lubricant for aviation engines. The viscosity of any oil, however, decreases as the temperature increases and for this reason the oil is cooled after each passage through the system. The exact method of cooling varies; sometimes it is passed around the carburetor and intake manifolds where two purposes are accomplished, that of cooling the oil and at the same time heating the fuel mixture. Another system is to pass the hot oil through copper tubing exposed to the air stream and acting as an oil radiator.

The course of the oil through an aviation motor lubricating system is from the outside reservoir, sometimes combined in the oil cooling device, under pressure through a hollow crankshaft to the main bearings and then to the connecting rod bearings. It is then forced either through a drilled passage in the connecting rod or through a small pipe attached on the connecting rod to the piston pin and its bushing. A separate line leads to all camshaft bearings. The oil thrown off the crankshaft bearings and piston pins lubricates the cylinder walls then joins that from the camshaft bearings in falling to the bottom of the crankcase into the sump. From here it is picked up by the scavenging suction pump and returned to the oil cooling system. The timing gears or chain are lubricated either by separate oil lines or by excess oil from the crankshaft.

Valves.—To permit the greatest possible amount of gas mixture to enter the cylinders and the quickest and most complete expelling of burned exhaust gases, the valves are made as large as possible. Very often four valves per cylinder, two intake and two exhaust, are provided and operated from a common rocker arm having a forked end. Four small valves will provide more opening per area of combustion chamber than will two larger ones.

In almost every case the valves are placed in the cylinder head and each set is operated by a separate camshaft, one camshaft operating all the intake valves and another operating the exhausts. In some engines the camshaft is located in the crankcase and push rods operate the rocker arms. Other engines have the camshafts mounted overhead on top of the cylinders, the shaft being operated through a train of gears from the crankshaft. In the latter design the cams are either in direct contact with the valve stems or bear directly on the rocker arms.

The valves are returned to their seats by the action of multiple springs. One type of construction is to have one spring inside of another. Another construction is to have several helical springs, say six, placed in a circle, the valve stem being in the center of the spring cluster.

In the radial engines the cam mechanism is placed in the crankcase and the rocker arms operated by long push rods.

Carburetion.—Aviation carburetors present a great field for experimentation. Carburetion is one of the features of aviation not yet perfected but rapidly approaching that stage.

The great number of cylinders used and their suction power necessitates a separate carburetor mixing chamber for every few cylinders, seldom more than four being fed from one chamber. Some carburetors have one large float chamber supplying gasoline to two or more mixing chambers. The butterfly throttle valve controls in this case are synchronized. Other types of construction provide a separate carburetor for each cylinder bank or equal collection of cylinders.

Floats, float chambers and shut-off valves are so designed as to prevent the float sticking, even at a considerable angle, and at the same time to supply the proper mixture to the cylinders.

Atmospheric pressure lessens with altitude and this fact bears directly on carburetor function. There is less pressure on the gasoline, less suction effort exerted and less compression pressure in the cylinder combustion chamber. The drawbacks are somewhat overcome by changing the mixture as altitude increases. This results in providing a more powerful explosion in proportion, up to a certain degree.

Superchargers are sometimes used to inject more air and oxygen and at the same time increase the compression pressure and supply more suction on the carburetor. The supercharger is used especially for high altitude flying. These devices are mounted between the cylinder and carburetor, taking the gas out of the latter and forcing it, under pressure, into the former. Another method used for high altitude work is to take along pure oxygen in a tank for use above fifteen or eighteen thousand feet.

Air commerce regulations require that fuel feed to the carburetor must be by gravity. The fuel may be pumped from the

main tank, if located below the carburetor level, to a gravity tank capable of holding an amount proportionate to the size of the engine. The gravity tank is located above the level of the carburetor. Gauges must be provided indicating the rate of flow of gasoline from tank to tank or indicating the quantity in the gravity tank.

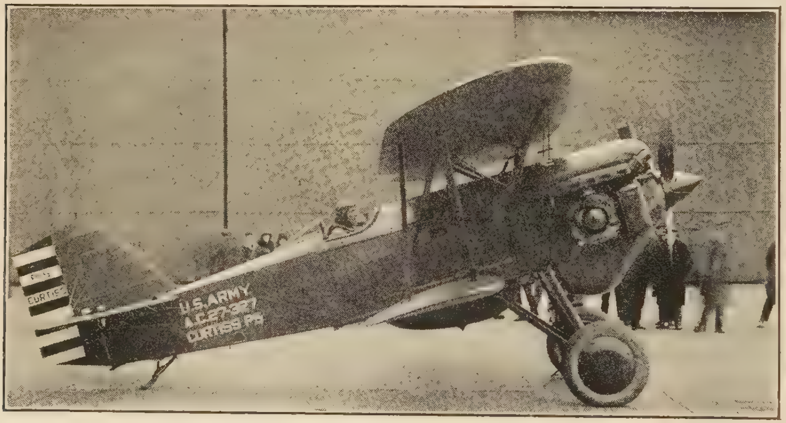


Fig. 43.—Curtiss "Hawk," showing supercharger installation.

A gasoline of higher gravity test than necessary for automobiles is invariably used, although some aviation motors will operate quite satisfactorily on ordinary commercial gasoline. It is much better to use the special aviation grade of fuel to insure both long motor life and uninterrupted service.

Ignition.—The ignition of an aëronautical engine is invariably accomplished by two magnetos operated independently of each other, each firing its own set of spark plugs simultaneously. This insures better and quicker ignition of the gas in addition to insuring operation on one ignition system in event of failure of the other.

A battery as a source of current is very seldom used except in cases where electric starters are used. Two distributor heads and two sets of breaker points are then used, each one firing a set of spark plugs.

In either case the advance and retard controls for both systems are synchronized and accomplished from the pilot's cockpit.

The spark plugs are specially constructed to radiate heat quickly. Wiring is of very substantial material, well insulated and kept as far as possible from hot surfaces and oil.

Propeller Speed.—It is well known that an engine's power increases as its revolutions per minute are increased. This however, is not true of a propeller. The efficiency of a propeller falls off rapidly above 1,400 r.p.m. In order, then, to incorporate the advantage of high engine speed and normal propeller speed, it is sometimes necessary to gear the propeller down. Motors are more often designed to operate directly on the propeller because, even though gearing allows more engine power to be developed and relieves the crankshaft of propeller centrifugal stress, the gearing adds more weight and parts together with a certain horsepower loss used up in operating the gearing. The average gear ratio, when a reduction is used, is 2,100 r.p.m. engine speed to 1,250 r.p.m. propeller speed.

This chapter is an outline of general engine requirements and practice, each make of engine incorporating its own individual method of approaching the ideal in much the same manner pursued by automobile manufacturers. Seven types are used in aviation, as follows: the upright cylinder-in-line, the upright V banks, the inverted or up-side-down V, the "X", the radial, the Caminez and the rotary, the two latter being now almost obsolete.

To give a detailed description of each make of each type would, of course, be impossible within the space available, but in the following chapter is explained the operation of representative makes of the different types. When you understand these, others will be easy to grasp.

Engine starters used on airplanes are not as standardized and conventional as those used on motor cars. The automobile engine starter system consists of a generator from which the electrical energy is stored in a battery which is used in turn through a motor to turn the engine over. These three units add considerable weight and are not usually acceptable to the airplane designer, although some planes of the heavier transport and bombing types are provided with the electric starting system.

A very few air starters are used. This system consists of a small multiple cylinder air pump, a tank in which to store the compressed air and the necessary valves and engine attachments. When

it is desired to start the engine with the air starting system, a valve is opened which admits the compressed air to certain engine cylinders, forcing their pistons down and forcing the piston up in the cylinder that is on its compression stroke, until it passes the firing point and is driven down again under its own explosive power. The air is admitted to the proper cylinder at the proper time through a rotating valve that uncovers and closes ports leading to the separate cylinders.

One of the most common types of airplane engine starters is called the "inertia" type. This device consists of a small flywheel, the necessary gearing to crank this small flywheel to a high rate of speed, and an engaging clutch that, at the proper time, connects the small flywheel to the engine.

The operation of the inertia starter, of which the Eclipse is a representative make, depends upon the storage of energy in the small flywheel which is made to revolve at a very high rate of speed by hand cranking. The small flywheel is caused to revolve at this high rate of speed through multiple gearing to the hand crank. The hand crank is revolved, starting the operation rather slowly until quite a speed has been obtained when greater force is exerted on the crank bringing the starter flywheel up to its maximum number of revolutions which occurs at about seventy-five or eighty revolutions per minute of the hand crank. The hand crank is then removed, but the starter flywheel continues to revolve rapidly. The operating rod is moved, which causes a jaw clutch on the starter to engage with a corresponding jaw clutch on the cranking extension of the engine. The energy stored in the starter flywheel is then communicated to the engine through a series of reduction gears and cranks the engine until the energy is either spent or the engine starts. The starter is thrown out of engagement with the engine automatically as soon as the engine starts. If the engine fails to start, the starter jaw clutch is disengaged by moving the operating rod in the opposite direction to that of engaging and the operation of cranking the small starter flywheel is done over again.

The Eclipse inertia starter requires no lubrication, this being taken care of in the materials used in its construction. It is possible to crank an engine up to and including 1,300 cubic inches displacement with their Series "6" starter. If a booster magneto is provided

in the ignition system of the engine, its use will help starting especially in cold weather, although not absolutely necessary.

While starters will be found on most engines of high power, with their consequent difficulty in hand starting, cranking the engine by the propeller is still the vogue on engines of one hundred to two hundred horsepower.

CHAPTER VIII

DETAILS OF AIRPLANE ENGINES

THE Packard gasoline aëronautical engine, manufactured by the Packard Motor Car Co., of Detroit, is a very excellent type of aviation motor and many of its characteristics will be found in other makes.

This engine is made with either twelve or twenty-four cylinders. They are high-powered engines, from 600 to 1,250 horsepower, and therefore incorporate all the requirements of the highest grade engines.

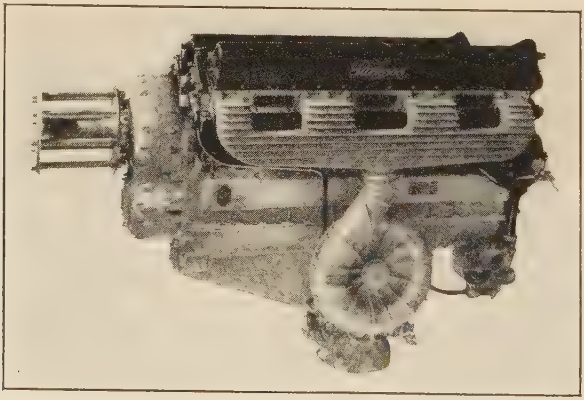


Fig. 44.—Packard twelve-cylinder engine equipped with supercharger.

The most noticeable departures from automobile engine design are in the cylinder construction, multiple valves, multiple valve springs, and the dry sump oiling system.

The cylinders are made from a drawn steel tube to which a forged combustion chamber head is welded. On the outside of the

cylinder a sheet metal water jacket is welded. A valve housing unit joins each bank of six cylinders, being bolted in place. This cylinder construction retains the advantages of the single cylinder type, in that an individual cylinder is easy of replacement, but the whole is rigid and clean of design. The cylinder and valve housing assembly is mounted on the engine as a unit and may be removed as such.

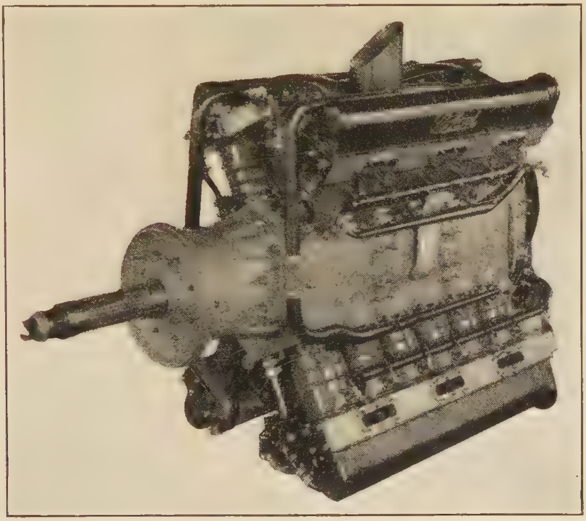


Fig. 45.—Packard twenty-four cylinder "X" engine.

Each cylinder has two inlet and two exhaust valves of the tulip type. Some models use seven and other models use ten helical valve springs on each valve. The pistons are of aluminum alloy made in two types, one for high compression and one for medium compression.

A very good feature of construction is that the main bearing caps are attached to the crankcase by long through bolts. The upper ends of these bolts pass through crabs that fit over the cylinder hold-down flanges, thus making a very strong and rigid unit.

The connecting rods are of the articulated type, using babbitt bearings integral with the big end of the connecting rod.

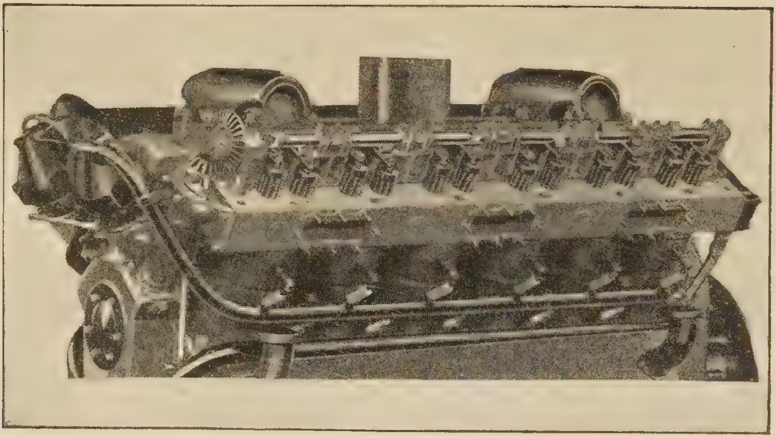


Fig. 46.—Valve spring cluster.

The steel cylinders have a hold-down flange placed some distance above the lower end of the barrel. This makes the barrel extend into the crankcase somewhat, preventing oil from collecting in the cylinder in the case of the inverted or upside down types. The top of the cylinder is a flat ground surface to which the valve housing is bolted by long studs in the cylinder head. Between the cylinder head and the valve housing is a copper-asbestos gasket. The cylinder is so constructed, however, that no explosive pressure reaches this gasket.

The aluminum valve housing is a casting with machined surfaces. It is made so as to collect the water circulated through each cylinder jacket and send it through a single outlet at the front of the engine. This housing distributes the gas mixture to each of the six cylinders in that particular bank to which it is attached, receiving the mixture from two carburetor manifold connections. The same housing forms the exhaust passages, each two adjacent cylinders having their exhausts guided into a single outlet, and acts as a support for the camshaft bearing pedestals and valve stem guides. The valve housing is so fastened to the six individual cylinders as to form a rigid cylinder block.

The oil is drawn from an outside reservoir through fine mesh

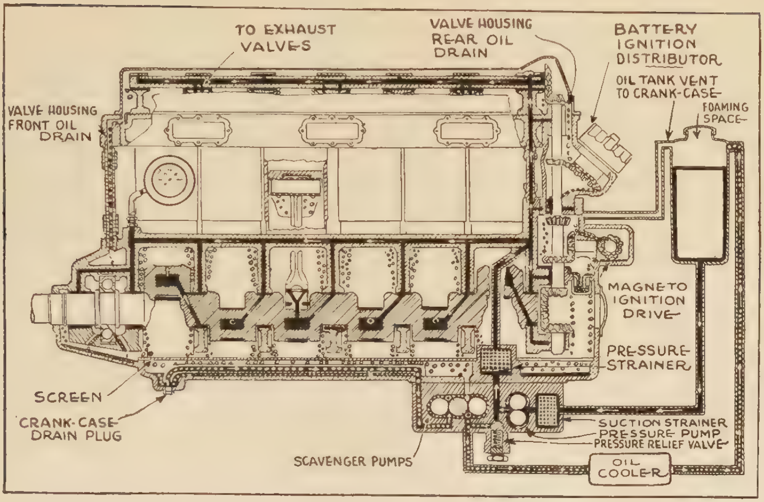


Fig. 47.—Packard aviation engine oiling system.

strainers by a combination suction and pressure gear pump. It is then sent to all bearings, main, connecting rod, camshaft and piston pin bushings, under pressure. The exhaust valve stems are cooled by oil circulated through passages drilled in them.

The excess oil thrown from the bearings after lubricating the cylinder walls falls to the lower half of the crankcase, or oil pan, passing through a screen which covers the entire bottom part of the oil pan and then goes into a sump. It is pumped from the sump by either or both suction scavenging pumps in the pump unit and returned to the outside reservoir after passing through a cooling device.

The scavenging pumps consist of three enclosed gears, one on the water pump shaft, one on the oil pressure pump shaft and

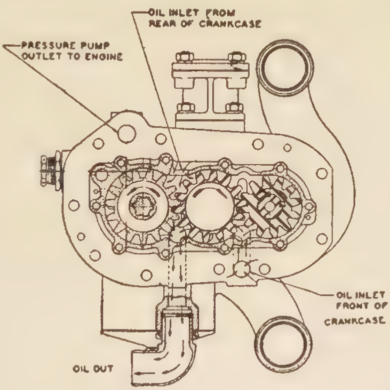


Fig. 48.—Scavenging pump assembly.

one on the fuel pump shaft. One scavenging pump drains the front of the crankcase and the other the rear of the crankcase.

Two one-and-one-quarter-inch hose connections are provided on the oil pump for the "oil in" and the "oil out" connections. These markings are cast on the oil strainer cover so as to indicate the purpose of the two connections.

A thermometer is placed in the oil circuit, preferably before the oil enters the cooling device, but in either case the indicating head of the thermometer is marked whether it indicates "oil in" or "oil out" temperature. The oil is pumped into the outside reservoir near its top and the lowest part of the reservoir is slightly higher than the inlet connection on the oil pump. The top of the reservoir is vented and the piping is as direct as possible, avoiding any low points in which congealed oil might collect in cold weather.

Engines are equipped with three different forms of ignition, depending upon the selection of the user. One system uses double magnetos with two independent drives; another uses a battery-generator system with two separate distributors; while the third employs two twelve cylinder magnetos each firing a set of spark plugs independent of each other. The latter system will be found most common. The two magnetos are mounted on a horizontal bracket bolted to the rear of the crankcase. The magnetos are driven at one and one-half times engine speed through adjustable couplings. The advance arms on the two magneto breaker boxes are connected to a control shaft and lever, operated by a spark advance control in the pilot's cockpit.

Inverted Engines.—Some models of aëronautical engines will run upside down. The cylinders are head down and the crankcase on top. They have four major advantages over upright types. They allow the pilot to have much better vision; the higher center of thrust insures better flying qualities by offsetting the tendency of the plane to climb when full power is on; there is better accessibility for a mechanic working on the ground; and there is full gravity feed to the carburetors, thus eliminating complicated piping. Fire hazards are also reduced because any possible gasoline leaks are confined to the lowest points.

Both of the twelve-cylinder models use two Stromberg carburetors, each one supplying a bank of six cylinders. On the twenty-

four cylinder X engine, four carburetors are used, each one supplying six cylinders.

Radial Engines.—Certain types of engines are not used in automobiles but are quite common on airplanes. These types are the radial and the Caminez. The rotary, similar in construction to the radial, was much used years ago but has reached the obsolete stage now.

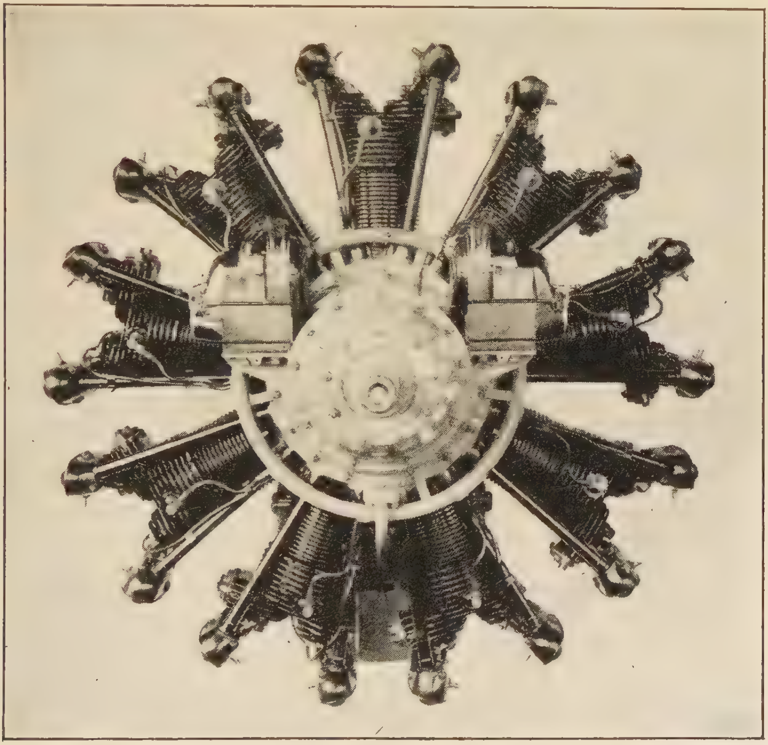


Fig. 49.—Wright "Whirlwind" radial engine.

The Wright "Whirlwind" radial is probably the most popular of the radial designs. This is the engine that carried Lindbergh across the Atlantic in addition to making any number of other historical flights.

The cylinders of a radial engine are arranged around a circular crankcase just as the spokes of a wheel are arranged around a hub. The cylinders and crankcase are stationary, as in ordinary engine construction, while the crankshaft and cams rotate.

The demand for lightness and compactness combined with maximum power output has caused the development of this type of engine to a high degree of efficiency.

In airplane engines, the end to which the propeller is attached is called the front, and in radials the cylinders are numbered consecutively in the direction of rotation, usually anti-clockwise viewed from the propeller end. The top cylinder is called number "one." The radial operates on the four-stroke cycle principle, using two magnetos that fire independent sets of spark plugs simultaneously and using one carburetor mixing chamber for each set of three cylinders in nine-cylinder engines. The number of cylinders varies somewhat with the different makes, the usual number being nine, although combinations of three, five, six, seven, eight and ten are used. The Wright "Whirlwind" and "Cyclone" are both of the nine-cylinder type.

In engines with an odd number of cylinders a very short crankshaft is used, having a single crankpin, or throw. In some cases it is supplied with counterweights to offset the weight of the opposing pistons and connecting rods. To the crankpin is fitted a master connecting rod with a very large diameter bearing flange. Equally spaced around this large flange are the other connecting rods, or link rods. The link rods are fastened to the bearing flange by pins and bushings. The Wright bearing flange, integral with the master rod, is split similarly to an ordinary automobile engine bearing, and the two halves are held together by four bolts.

The Pratt & Whitney "Wasp" and "Hornet" engines use a solid bearing flange and a crankshaft that comes apart so as to assemble the master rod and bearing flange on it.

The crankshafts are hollow throughout their length and used to distribute oil to all parts of the engine. The Wright crankshaft rides in four bearings—a ball thrust bearing, two main roller bearings and a plain bearing in the rear section where the oil is admitted. The master bearing flange is provided with steel-backed babbitt while the link rod bushings are of bronze.

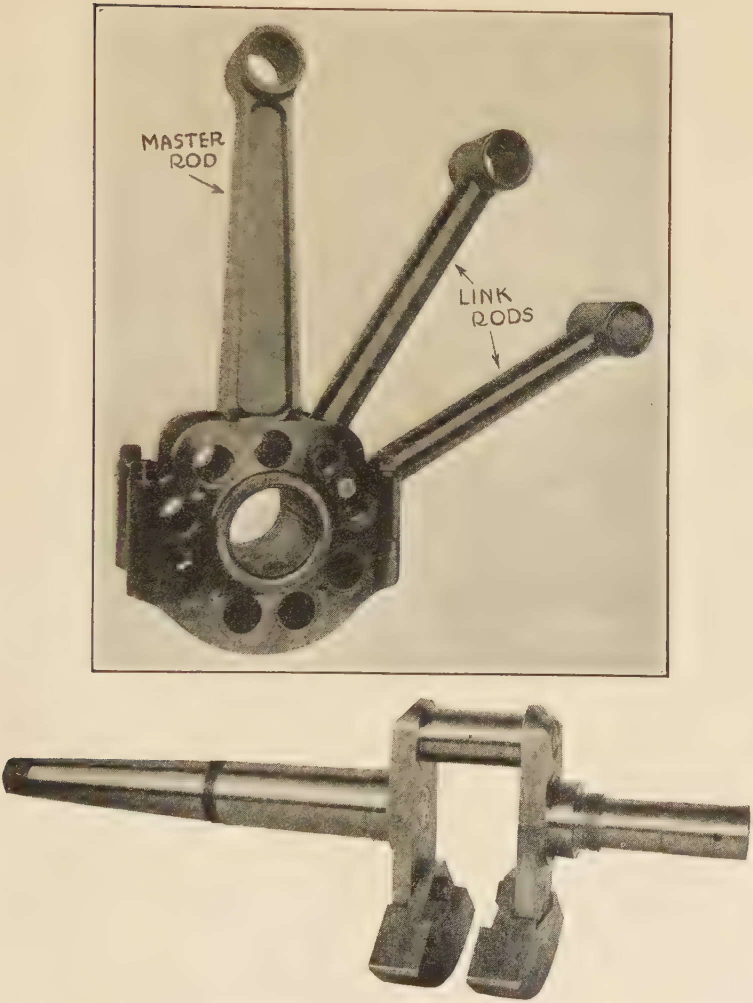


Fig. 50.—Wright "Whirlwind" crankshaft and connecting rod assembly.

To visualize the action of the radial engine, refer to Fig. 52. The upper left hand illustration shows the master rod of number one cylinder with the piston on top dead center, about to start down

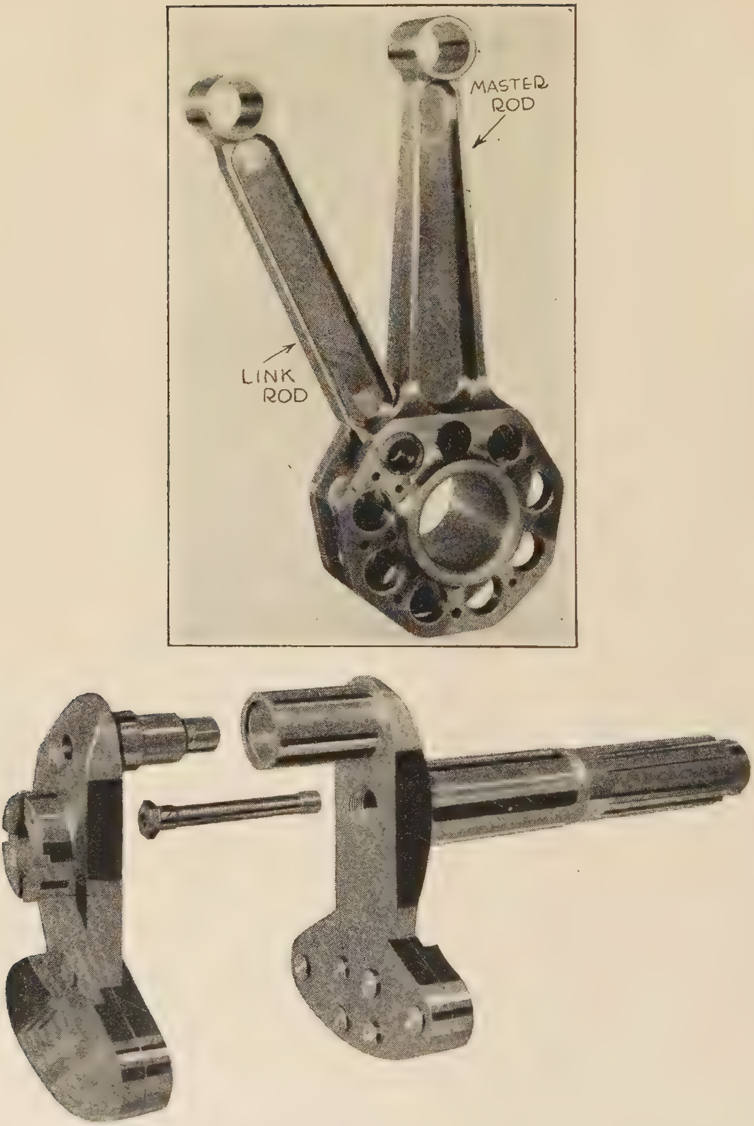


Fig. 51.—Pratt & Whitney "Wasp" crankshaft and connecting rod assembly.

on the power stroke for instance. The other link rods are shown in their relative positions. Notice the position of the rod for cylinder number three. In the lower left hand illustration number one piston is part way down on its power stroke and the crankshaft has rotated about one-quarter revolution, placing number three piston on top dead center ready for its power stroke, while number two piston is coming down on its intake stroke. In the upper right hand illustration, number one piston is at bottom dead center of the

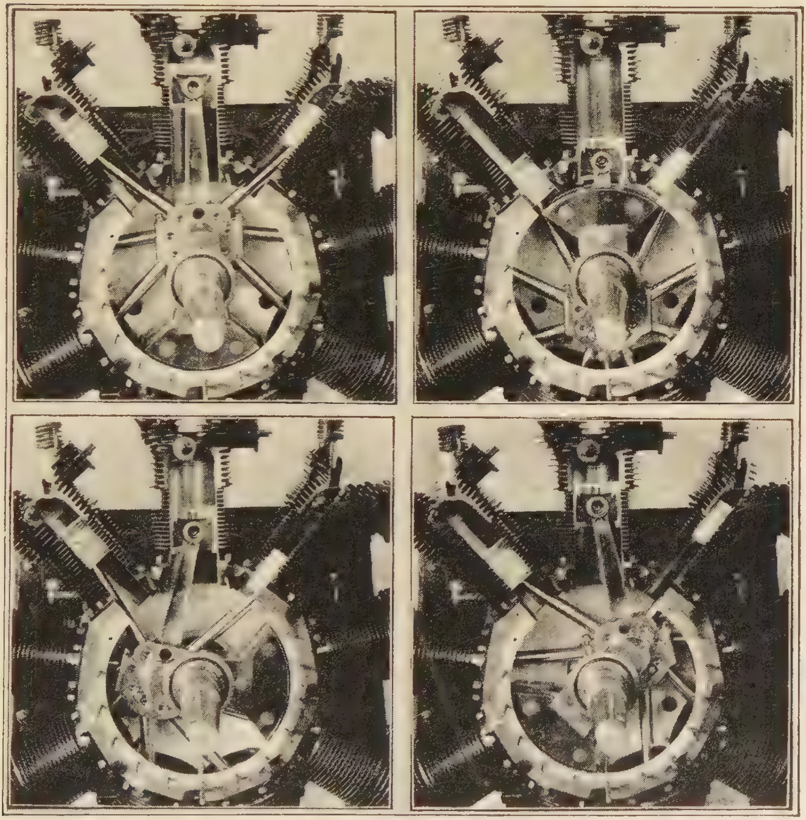


Fig. 52.—The strokes of a nine-cylinder radial engine, Wright "Whirlwind."

power stroke, number three has just fired and number two has all but completed its intake stroke. Notice that the master rod flange is down now and the counterweights are up, the crankshaft having completed one-half revolution. In the lower right hand illustration, number one piston has just about completed its exhaust stroke, number three is just starting its exhaust stroke and number two is about halfway up on its compression stroke.

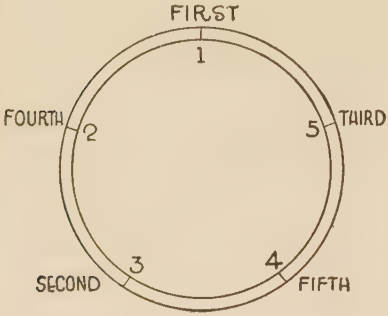


Fig. 53.—Firing order of an uneven number of cylinders.

In all single crankpin radial engines there is an uneven number of cylinders. This is necessary in order that a uniform firing order and torque may be maintained. Every other cylinder is fired in order, the firing proceeding through equal angles with all cylinders. The firing order of a five-cylinder engine is 1, 3, 5, 2, 4, there being a lapse of one cylinder between each impulse or explosion. This is illustrated in Fig. 53. The figures *1, 2, 3,* etc., inside the circle indicate the cylinder number while the words *first, second, third,* etc., outside the circle indicate their order of firing. As can be seen, a cylinder is skipped each time.

With an even number of cylinders, using a single crankpin, it would be impossible to obtain equal firing angles, because it would be necessary to fire two adjacent cylinders together or else skip more than two cylinders. For instance, the firing order of a six-cylinder engine, using a single crankpin, would have to be 1, 3, 5, 6, 2, 4, and then through two idle spaces back to No. 1. There would be no cylinder fired between 5 and 6, and there would be two cylinders not fired between 4 and 1, these being 5 and 6. This order of firing would produce unbalance and a very uneven torque.

Therefore, in radial engines of an even number of cylinders, more than one crankpin is used and an uneven number of cylinder connecting rods are attached to each. This in reality makes two or more engines of an uneven number of cylinders mounted on a single crankshaft. A six-cylinder engine would make two with three

cylinders, a ten-cylinder two with five cylinders, etc. Each multiple of an uneven number is then fired so as to produce an even flow of power impulses and blend in with the other multiple. An exception to this rule is the eight-cylinder Curtiss "Chieftain." This engine consists of two four-cylinder radial engines operating on two crank-pins of a common crankshaft.

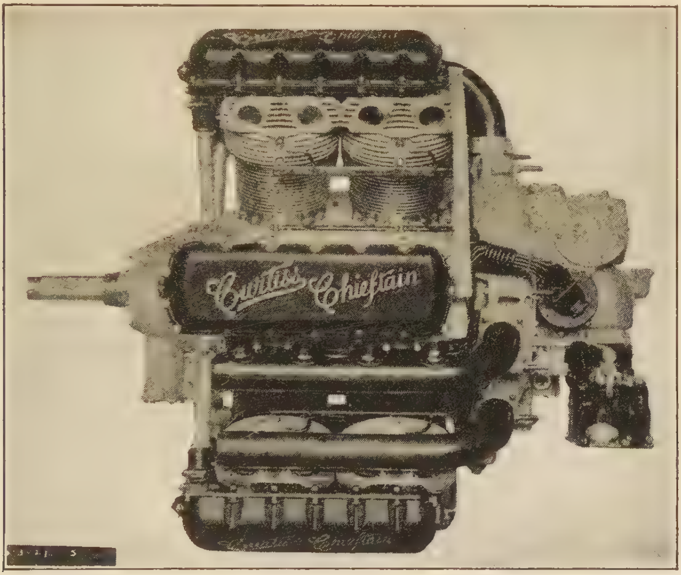


Fig. 54.—Curtiss eight-cylinder radial "Chieftain" engine.

The Wright "Whirlwind" crankcase is peculiar in that it is made up of five distinct sections or parts cast of aluminum alloy. The front section, which includes the nose plate, contains the thrust bearing housing, brackets for the magnetos, and the magneto and cam drive gears. The next section back, the intermediate section, contains the cam and valve tappet mechanism and the front main crankshaft bearing housing. The next section is the main part of the crankcase and is provided with the cylinder pads, and rear main crankshaft bearing housing and the intake passages. The extreme rear section contains the fuel and oil pump drives, gun synchonizers

and tachometer drive. It is also the mounting for the engine starter and a housing for the main oil strainer.

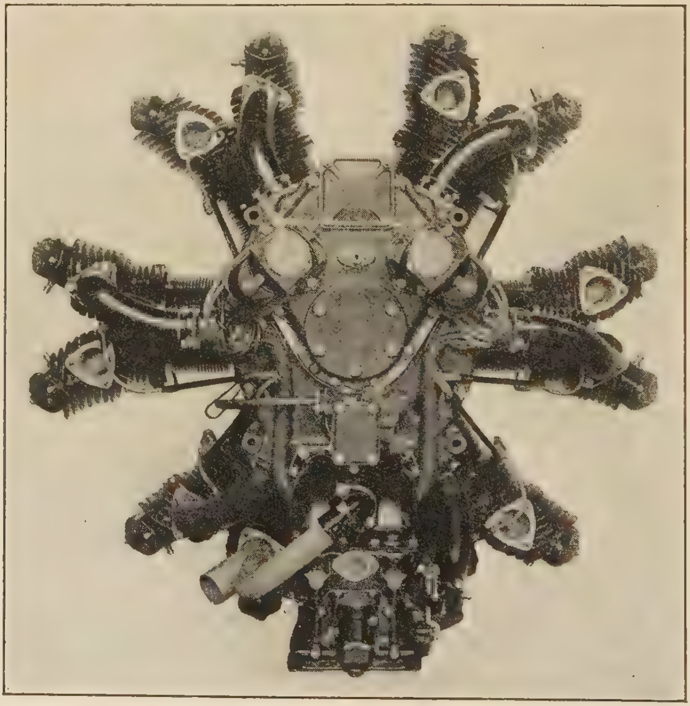


Fig. 55.—Curtiss six-cylinder radial engine.

In all "Whirlwind" models the cam is located in the intermediate section, second from the front. The cam is a hardened steel ring with eight raised lobes on the outside and an internal gear cut on the inside to mesh with the cam operating gear on the magneto drive shaft. The cam is riveted to an aluminum hub which rides on a steel sleeve on the crankshaft. It is rotated in the opposite direction and at one-eighth crankshaft speed. As the cam ring revolves, the lobes lift conventional roller-type tappets operating in cast-iron bushings (J–4 Model) or in steel bushings (J–5 Model),

the bushings being a push fit in the intermediate section casting. The upper end of the tappets has a hardened steel socket into which fits a ball on the lower end of the long push rod. The Model J–4A and J–4B push rods are adjustable for clearance on their upper ends. The J–5 push rods are of specially heat-treated nickel-steel tubing with balls pressed into both ends. The balls on the upper ends fit into hardened steel cups which are a loose fit inside the tappet clearance adjusting screws.

The rocker arms of the J–4A and J–4B models are carried on forked supports of forged steel. The J–5 rocker arm housing, being semi-enclosed, also forms the support for the rocker arm pins. The push rods are housed in a steel tube as a protection from dust, one end of which is fastened to the intermediate section and the other end to the rocker arm housing. Pressed aluminum caps fit on the rocker arm housings.

Both the intake and exhaust valves on the model J–5 are of the tulip type. In order to keep the exhaust valves as cool as possible, they are filled with salt and sealed at the top with a hardened plug. The valve seats are rings of aluminum bronze. They are first shrunk into the cylinder head and then the small shoulder left at the top is rolled over into a recess in the valve port. The valve springs of the J–4A and J–4B consist of two concentric helical coils of round steel wire per valve. The J–5 valves have three such springs per valve.

Two Scintilla magnetos furnish the ignition, the right hand one firing the front spark plugs and the left hand one firing the rear spark plugs, both at the same instant. The Stromberg model NA–T4 carburetor is used on the J–5, having three barrels or mixing chambers with but one float chamber. The carburetor is attached to an oil-jacketed manifold at the bottom of the crankcase main section. The purpose of the oil jacket is to lead the hot oil around the cold manifold, heating the gas mixture and at the same time cooling the oil. From the manifold the gas is led to the cylinders through three steel tubes, one supplying cylinders 2, 5 and 8, another supplying cylinders 1, 4 and 7, and the third supplying cylinders 3, 6 and 9. In this manner the inertia of the gas is kept nearly constant.

The "Whirlwind" lubrication system is full force feed except for the cylinder walls, piston pins and accessory drive gears, the

latter being lubricated by splash. Oil is drawn from the outside reservoir and sent to the crankshaft, hollowed for the purpose, reaching the crankpin bearing through a drilled passage, and is sent on to the cam bearing and to passages near the front end of the crankcase which lead to the magneto drive bearings. The master rod flange contains passages that lead the oil to the link rod, knuckle pin bearings. The gears, shafts and bearings in the rear section of the crankcase receive oil sprayed from the rear crankshaft bearing. The oil spray from the cam drive shaft, cam bearing, and magneto shaft bearing lubricates the gears and valve tappets. The rocker arm pins are supplied with Alemite grease connections.

A flat steel plate mounting flange is provided for attachment to the front of the airplane fuselage to which the engine is bolted by eight ⅜-inch S. A. E. alloy steel bolts.

The specifications of the famous J–5 Wright "Whirlwind" are interesting:

Average horsepower at normal revolutions per minute	220
Normal revolutions per minute	1800
Guaranteed brake horsepower at sea level with aviation gasoline	200
Number of cylinders	9
Bore and stroke	4½″x5½″
Piston displacement	788 cu. in.
Compression ratio	5.2
Rotation looking at propeller end	anti-clockwise
Tachometer shaft speed	½ crankshaft
Average weight of engine complete with carburetor, two running magnetos, spark plugs, high tension wiring and gun drives. Without oil, exhaust pipes, exhaust flanges, starting device, fuel pump, propeller hub, flange and bolts. Add 13 pounds for propeller hub assembly	515 lbs.
Over-all diameter outside of rocker arms	45″
Ignition	Double with two magnetos
Magneto speed	1⅛ times crankshaft
Fuel consumption: lbs. per horsepower hour, at 200 h.p. and normal r.p.m.	.53
Oil consumption, lbs. per h.p. hour, not over	.035
Best efficiency oil outlet temperature	120° F.
Maximum permissible oil outlet temperature	180° F.

The Wright engines are air-cooled, the thin fins on the cylinders dissipating the heat. Metal cowling is sometimes used on the front of them to direct the air blast to the cylinder head, for streamlining and to improve the general appearance of the engine. Openings in this cowling are usually provided with a shutter arrangement, permitting regulation of the cooling air in cold weather.

The Pratt & Whitney "Wasp".—Like the "Whirlwind" crankcase, the "Wasp" engine crankcase is divided into five sections, all bolted together into one unit when assembled. The Pratt & Whitney engines incorporate a supercharger in the rear section, being made as a part of the engine. Each cylinder has an individual intake pipe leading from the supercharger housing to the cylinder inlet valve port. With the exception of this feature and the solid master rod bearing flange with its split crankshaft, the two engine types are very similar, although the "Wasp" has a rated horsepower of 410.

The "Wasp" specifications:

Average horsepower at normal revolutions per minute........ 410
Normal revolutions per minute.......................... 1900
Number of cylinders.................................. 9
Bore and stroke.............................. 5¾"x5¾"
Piston displacement............................ 1344 cu. in.
Compression ratio.................................. 5.25
Rotation looking at propeller end.................. anti-clockwise
Tachometer shaft speed.......................... ½ crankshaft
Maximum weight................................. 650 lbs.
Over-all diameter outside of rocker arms................ 50⅝"
Ignition............................ Double with two magnetos
Fuel consumption: lbs. per horsepower hour at rated horsepower, not more than.................................. .55
Oil consumption, lbs. per h.p. hour, not over................ .035
Oil temperatures........................ same as "Whirlwind"

Both engines use a scavenging oil pump and relief valves for the regulation of the oil pressure. The "Wasp" rocker arms are lubricated by manually filled oil reservoirs on each bearing.

The Caminez Engine.—This engine is quite a novel departure from accepted internal combustion engine design. It is the invention of Mr. Harold Caminez, Vice-President and Chief Engineer of the

Fairchild Caminez Engine Corporation. Mr. Caminez was for a long time in charge of engine design for the Engineering Division of the U. S. Army Air Corps at McCook Field, Dayton, Ohio. While engaged there he had the advantage of the government's engineering laboratories in which to perfect his design.

While the engine, which is of the four-cylinder stationary radial air-cooled type, retains the four-stroke cycle principle as applied to the piston travel, the four strokes are accomplished during one revolution of the crankshaft instead of during two revolutions as in ordinary engine construction. The result is a high power output at comparatively low propeller speed and power impulses equivalent to an eight-cylinder engine, giving eight power impulses for each two crankshaft revolutions, the same as the ordinary eight-cylinder engine. The Caminez model 447–C develops one hundred and forty-five horsepower at 1,100 revolutions per minute with only four hundred and forty-seven cubic inches of piston displacement. This is the highest power output, per unit of displacement, obtained so far with an air-cooled engine not using a supercharger.

The weight of the engine is about 350 pounds, or approximately 2.42 pounds per horsepower. The over-all width and height of the engine is only thirty-six inches, resulting in very low head resistance. Another factor in favor of this engine is the very few parts. It has only four cylinders, no valve timing gears and no crankshaft counterweights.

By accomplishing four piston strokes in each revolution instead of in two revolutions, this engine delivers high power output without having to resort to high speed in revolutions per minute. In the same manner the engine also obtains the effect of a two-to-one propeller reduction without the increased cost, complication and weight of gearing.

Construction and Operation.—The four pistons are arranged radially around the central cam, as shown in Fig. 56. Each piston is provided with a large roller mounted on the piston pin, the roller making contact on the "figure eight" cam. A link arrangement is used to connect the pistons together and the shape of the cam is such that the piston rollers are made to follow the outline of the cam by means of the action of the connecting links. The driving cam is mounted directly on the propeller shaft by splines. The four

cylinders are set at right angles to each other and act only as guides for the reciprocating pistons.

At each end of the piston pin is what is called an intermediate link holder to which are attached the piston connecting links. The use of these intermediate link holders, which are free to turn on the piston pin, equalizes the tension on the piston connecting links and overcomes any cylinder misalignment or any inaccuracy of the drive cam. They automatically compensate for the clearance between the cam and rollers also. When assembled, the clearance between the cam and the piston rollers does not exceed 1/64 of an inch, but the engine will operate satisfactorily with a clearance of 1/16 of an inch.

The Cycles.—While reading the following explanation of the cycle operation, refer to Fig. 56. Position *1* shows the piston of cylinder *A* at top dead center. Revolving clockwise, or to the right facing the drawing, in position *2* this same piston has moved down while the cam rotated forty-five degrees. The explosive force of the gas mixture acting on the piston has been transmitted through the roller to the cam at point *F* forcing the cam around which in turn has changed the position of the other pistons.

Position *3* shows the position of the cam after ninety degrees of

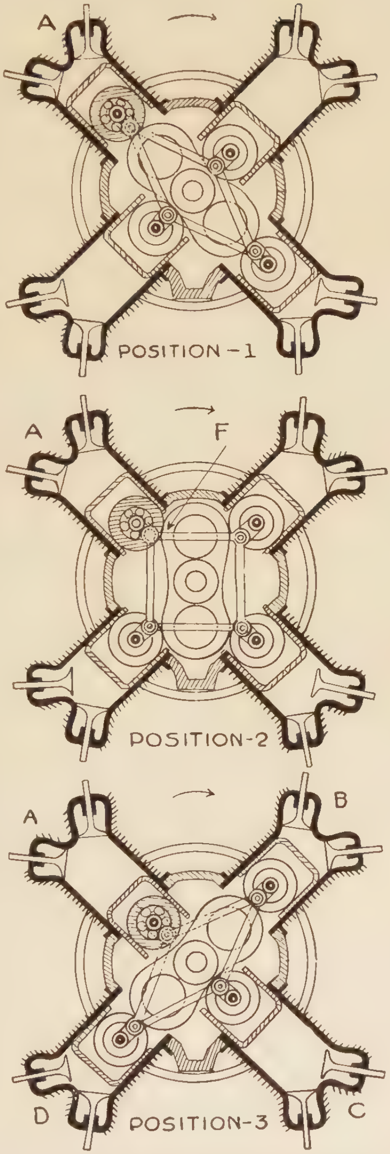


Fig. 56.—Operating principle of the Caminez engine.

rotation, placing the piston in cylinder *A* at the bottom of its travel or at bottom dead center. It can be seen that the piston of each cylinder has completed a full stroke while the cam and propeller shaft have made only one-quarter revolution. The piston of cylinder *A* has completed a power stroke, piston *B* a compression stroke, piston *C* an intake stroke and piston *D* an exhaust stroke. One complete engine cycle has been completed in ninety degrees of rotation, or one-quarter revolution of the propeller shaft.

Continuing, when the cam has rotated another ninety degrees, cylinder *A* will have completed its exhaust stroke and be about to intake. Another ninety degrees and it will have completed the intake stroke and about to start up on the compression stroke. One more ninety-degree turn and the piston of cylinder *A* has reached top dead center and is ready to start down on its power stroke again. Therefore, in three hundred and sixty degrees of travel, or one complete revolution, the engine has completed a four-stroke cycle in each cylinder and has transmitted four power impulses to the propeller shaft. In the ordinary engine of a like number of cylinders, the shaft would have received only two power impulses.

It is possible to obtain excellent balance in the Caminez engine, due to the fact that opposing pistons are traveling away from each other and therefore overcoming each other's swaying force. By having the pistons operate directly on the drive cam, thereby avoiding the long connecting rod length necessary in the conventional engine, a very compact arrangement is secured which makes possible a very sturdy construction, smaller size and therefore less head resistance. The cam engine also provides an individual bearing surface for each piston instead of having one connecting rod bearing take the entire load from all cylinders, as is the case in other radials using the articulated rod system.

The drive cam is a chrome vanadium forging, the bearing face being especially heat-treated and very hard. There is no direct sliding friction on the cam, as the piston rollers are special double-row roller bearings, the outer race of which acts on the cam and the inner race on the piston pin. This provides a rolling movement rather than a sliding movement as is the case in the ordinary bearing.

Due to the low speed of rotation, two-bladed propellers approximately ten feet in diameter, or four-bladed propellers approximately eight and one-half feet in diameter may be used.

CHAPTER IX

AIRCRAFT CARBURETORS

AS said before, a carburetor is a device that turns liquid gasoline into a vapor and then mixes this vapor with a definite amount of air. Liquid gasoline flows from the fuel tank through a pipe, entering the carburetor through what is sometimes called the needle valve, but more correctly the float valve. The float valve is opened and closed by the action of an arm attached to it and pivoted at one end, then attached to what is called a float at the other. It is necessary that there be in the carburetor, between the gasoline supply tank and the vaporizing jets, a separate constant level reservoir,

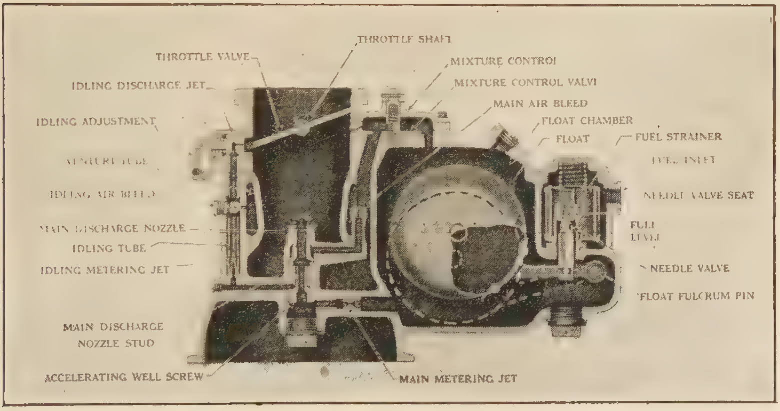


Fig. 57.—General carburetor construction.

called the float chamber. The action of the float mechanism is illustrated in Fig. 57, showing the design used in many Stromberg aircraft carburetors. With no fuel in the carburetor, the float drops down, leaving the float valve open. As gasoline enters from the

supply pipe, passing through the strainer before reaching the float chamber, the float, being buoyant, will rise and shut the needle, or float valve when the fuel reaches the level shown. When the engine is running and fuel is being drawn out of the float chamber to the main discharge nozzle, the float valve does not alternately open and close and the float rise and fall, but takes an intermediate position so that the valve is open just a sufficient amount to keep the fuel supplied and the level constant. The running level of the fuel is about one-eighth of an inch below that of the standing level. While the engine is running the vibration usually keeps the fuel splashing considerably above the running level.

The gasoline is then led from the float chamber through a passage to a small upright tube, in the upper end of which is a metered hole called a discharge nozzle or jet. The nozzle is placed in a larger tube, called a venturi tube, that is properly shaped and that leads directly to the cylinder combustion chambers. The opposite end of the venturi tube leads to the outside air. The suction of the cylinders, as the inlet valves are opened, draws the liquid gasoline through the nozzle and it is then mixed with the right amount of air in the venturi, thence to the cylinders. The amount of gas mixture passing to the cylinders is governed by a throttle or butterfly valve placed in the larger tube above the nozzle and operated by the pilot.

The Stromberg Motor Devices Company have succeeded in perfecting, as far as possible, a carburetor suitable for use on aviation motors that functions efficiently under the varying conditions found in flying. The fact that gas must be fed to the engine while at a steep bank, a climb or a dive, has led to the development of features not necessary in automobile carburetors.

It has been generally believed that a simple plain jet in a carburetor air opening of fixed size tends to deliver a mixture continuously becoming richer as the suction and air flow increases. This is not altogether true. As carburetors are now built, a plain jet will give a fairly uniform mixture as long as the engine is running at medium or high speed; but as the engine slows down in speed, the fuel delivery from the jet reduces sharply and not in proportion to the reduction of air flow. This is because of the fact that considerable suction force is lost in raising the fuel from the float level to the top of the jet outlet. The fuel level is, of course, below the top

of the jet when the engine is idle to prevent the fuel overflowing A certain amount of suction is also necessary to overcome the tendency of the fuel to adhere to the tip of the jet. At low engine speed and consequent low suction the discharge from a plain jet is illustrated in Fig. 58, the fuel clinging to the metal of the jet and being torn off intermittently in large drops. The adherance force is more or less constant but rather insignificant at high suction, exerting its greatest retarding effect at low suction.

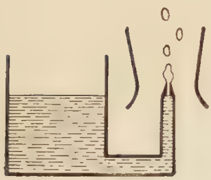


Fig. 58.—Fuel adhering to nozzle tip at low suction.

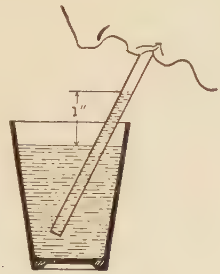


Fig. 59.—Suction lifting liquid without drawing any of it away.

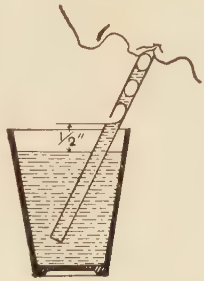


Fig. 60.—Suction drawing liquid by action of the air bleed.

To overcome this tendency the "air bleed" principle has been devised. Fig. 59 illustrates how suction may be used to lift a liquid above its level. The level of the liquid in the straw may be halted at any point by reduction of the suction exerted. But if a tiny hole were pricked in the side of the straw above the main liquid surface and the same suction applied, the air coming in the tiny hole would pass through the liquid in the straw in bubbles drawing small amounts of fuel up with it in a series of small slugs or drops, as illustrated in Fig. 60. The application of the air bleed principle is not perfect when used in this manner because there is still a certain distance that the fuel must be raised—from the level of the liquid to the tiny hole before the air picks it up. The large opening at the extreme bottom of the straw also prevents a very great suction being exerted through the small hole in the upper part of the straw because the suction force will naturally communicate itself to the point of least resistance—the larger hole.

In order to overcome these drawbacks the small hole is placed below the liquid level and connected to the outside air through a tube, and the hole at the bottom of the straw is made of just the proper size, as illustrated in Fig. 61, to supply the finely divided emulsion of air and liquid being formed in the straw.

All of the features just described, when incorporated into a carburetor jet, assume the form shown in Fig. 62. Such a jet supplies a substantially uniform mixture under steady velocity throughout its range of operation. The proportions of the mixture can be modified for low speed or high speed as desired by the proper selection of size of the air bleed and emulsion tube.

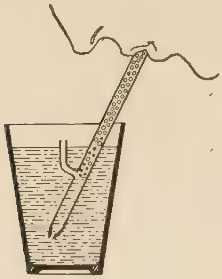


Fig. 61.—A better application of the air bleed.

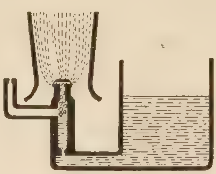


Fig. 62.—Carburetor nozzle with an air bleed.

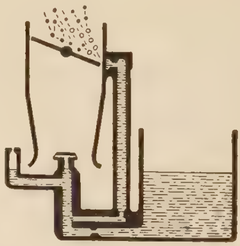


Fig. 63.—Air bleed and idling passage.

Because of the fact that the air flow at low engine speed does not have sufficient force to carry the fuel up from the jet to the throttle valve, the structure shown in Fig. 62 does not entirely meet the requirements of efficient carburetor function. Therefore a by-pass, or idling passage, is provided that carries the fuel up to the throttle valve and intake manifold when the suction is weak, opening into the passage above the throttle valve where the suction is greatest, as in Fig. 63. This idling passage is practically inoperative at open throttle because the greater suction has been transferred to the main metering jet and air from outside.

The venturi tube is made as a removable bushing so that the proper size may be inserted according to the air capacity of the engine. The main metering jet is also removable so that the proper size may be selected as necessary to give the fuel flow desired. The

air bleed for the main jet exerts very little effect on the mixture and very seldom need be changed.

The idling passage is provided with an air bleed passage for the purpose of reducing the suction on the idling metering hole to controllable limits, to provide a means of low-speed mixture regulation and to contribute to the operation of priming. The air bleed passage opening is slightly above the level of the fuel in the float chamber, the passage then leading down to the extreme bottom of the idling passage. Therefore, when the engine is idle, both the air bleed passage and the idling passage fill with raw fuel in a volume corresponding to a rich fuel charge for one cylinder. When starting the engine, if the throttle is closed, the first quarter turn of the propeller will draw this rich charge into the intake manifold before the air bleed flow through the idling jet system can begin. Waiting an interval of a few seconds, each quarter turn of the propeller will allow these passages to fill up again, supplying a priming charge for each cylinder. If priming is not desired, opening the throttle

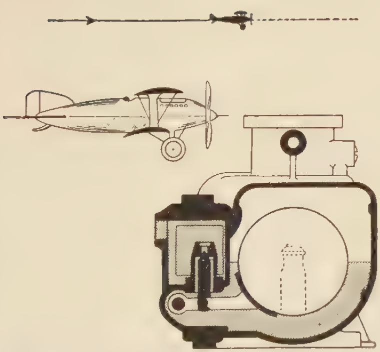


Fig. 64.—Level flight, normal feed to jet.

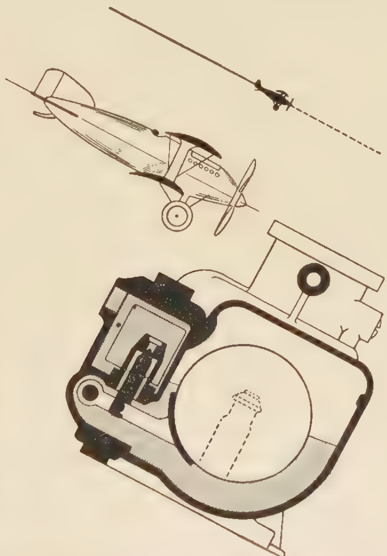


Fig. 65.—Dive, normal feed to jet.

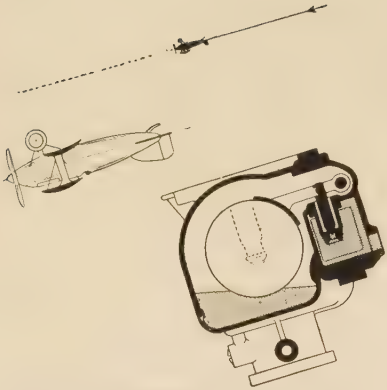


Fig. 66.—Continuous flight up-side-down, no fuel to jet.

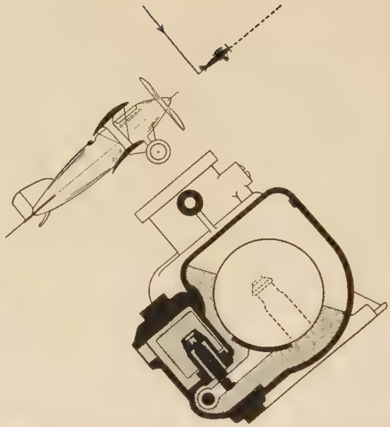


Fig. 67.—A zoom, following a dive, normal feed to jet.

about one-quarter will reduce the manifold vacuum so much that no priming action will take place.

Changing the size of the air bleed hole provides an adjustment for idling speed.

In airplane carburetors it is very necessary that the float mechanism operate positively at any angle and in any position of the ship where power is desired. It should also be so constructed as to prevent gasoline leakage in any other position. The float mechanism of the Stromberg airplane carburetors was designed with this end in mind and Figs. 64, 65 and 66 show the position of the fuel in these carburetor float chambers when the carburetor is in several different positions. Fig. 64 shows the condition while the ship is in normal level flight position. When the plane climbs, dives or skids sideways the action is normal because of the manner in which the float is suspended. When the plane is upside down, the float is not supported by the gasoline and the inlet valve shuts off, as shown in Fig. 66.

The operation of the float mechanism and the position of the fuel during different aërial maneuvers depend not only upon gravity, but also upon the motion and position of the airplane. The motion of the airplane involves inertia and, during certain movements, centrifugal force, while the position of the airplane determines the posi-

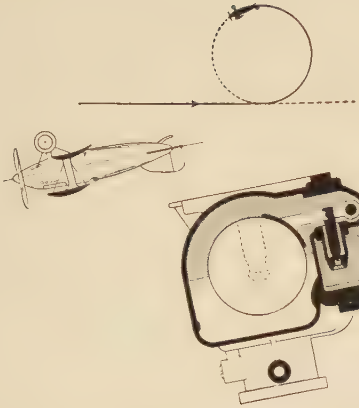


Fig. 68.—Loop, without stall, normal feed as long as pilot is hard against seat.

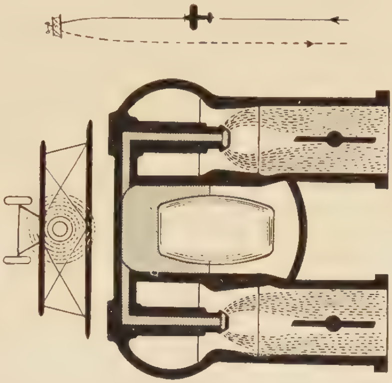


Fig. 69.—Vertical bank, normal feed to jet.

tion of the outlets from the float chamber relative to the earth. Figs. 67 to 70 show the position of the fuel in the float chamber during certain maneuvers, assuming that the carburetor is mounted with the float pivot toward the rear of the airplane. The ultimate result can be expressed simply in terms of the pilot's sensation of position, since his body is acted on by the same forces as the fuel mass. The carburetor float will function normally whenever the pilot is resting on his seat, leaning hard against the back or the sides of his seat, or tending to slide forward. If the position or motion of the plane is such that the pilot tends to leave his seat and be supported by the life belt, the same forces will cause the float to go up, that is, to close the float needle

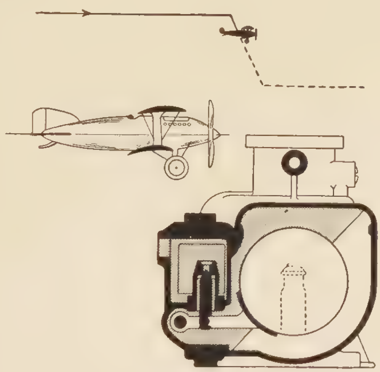


Fig. 70.—Violent drop, interrupted feed.

valve. At the same time the fuel will go to the top of the float chamber and cease to flow from the discharge nozzles. This action can occur when a violent gust of wind forces the airplane down so quickly that the pilot leaves his seat. In such case, the fuel will take the position shown in Fig. 70 and temporarily cease to flow from the discharge nozzles, even though the airplane be right side up.

In older airplane carburetor practice, the carburetor barrels and fuel discharge nozzles were located ahead of, or behind, the float chamber; with such an arrangement, when standing with tail down, or diving at a steep angle, the main jet was considerably above or below the fuel level. When above, there was a tendency for the mixture to be unduly lean; when below, there was a tendency for the fuel to leak out. In the newer Stromberg types, the fuel discharge nozzles are located in line laterally with the center of the float, with the result that the fuel flow is not disturbed in any normal flying position.

In the NA–Y5 *Duplex* type, which was designed for use in the limited lateral space of the Curtiss D–12 engine, two floats are used, both attached to the same lever and valve, one ahead of and one to the rear of the fuel discharge jet. As the carburetor is inclined, the fuel level rises on one float and goes down on the other but its position with reference to the discharge nozzle is not changed.

Fuel Level.—The level reached by the fuel in the float chamber depends somewhat upon the specific gravity, being slightly higher as the fuel is lighter. As set at the factory, these float valves will operate properly and hold the level sufficiently close with fuels ranging between 58 and 76 degrees Baume gravity.

Alterations in the level are obtained by the use of thicker or thinner gaskets under the needle valve seats.

The Altitude Mixture Control.—As the airplane ascends the atmosphere decreases in pressure, temperature and density. The weight of each air charge taken into the engine decreases with the decrease in air density, cutting down the power in about the same percentage. In addition, the mixture proportion delivered by the carburetor is affected, the mixture becoming richer at a rate inversely proportional to the square root of change in air density.

In the Stromberg line of airplane carburetors, two different

methods, the float chamber suction control and the air port control, have been employed for correcting this tendency toward enrichment of the mixture with increasing altitude. Both of these, however, operate by decreasing the suction tending to draw the fuel through the metering jet. The float chamber suction type of control operates to reduce the fuel flow by placing a certain proportion of the air passage suction upon the fuel in the float chamber so that it opposes the suction existing in the main discharge jet. The air port control operates by bypassing part of the air charge around the venturi tube and fuel jet, and reducing both the air velocity and suction existing at the main discharge jet. The air port type of control has the advantage that it slightly increases the air volume capacity of the carburetor with increasing altitude; but the allowable reduction of velocity past the jet reaches a limit at about 20,000 feet and this type of control is, therefore, not suitable for extremely high altitude service. The air port control also requires an increase in carburetor size which often prevents its use when space is limited, as, for instance, in the Vee of a twelve-cylinder engine.

Altitude Mixture Control Range.—As previously stated, the air port altitude controls are designed with a range of correction to about 20,000 feet, which means that with the control in the full lean position, the fuel flow is equivalent to that which would be obtained by the use of no control but with a fuel jet of 28 per cent less area. Similarly the float chamber suction type of control is made with a correction range of 25,000 feet, which is the equivalent of reducing the jet size 36 per cent. It will be obvious that the whole of this correction will only be available if the jet size is correct for ground operation. If a metering jet setting is selected which gives a mixture 10 per cent richer than necessary on the ground, relying upon the altitude control to obtain the proper ground and low flying setting, obviously the remaining correction available for altitude use will be less than if the ground setting were obtained with a smaller jet and the altitude control full rich.

The term "limit of altitude correction" refers to the maintenance of the "best setting," or leanest mixture for maximum power. After the limit of altitude correction has been reached, the plane can ascend 6,000 to 10,000 feet higher before the mixture will become so rich

as actually to cause the motor to lose power, although the fuel consumption will become unnecessarily high and the engine may run somewhat roughly.

Float Chamber Suction Control.—The method by which this operates may be understood by consideration of Figs. 71 to 73. This simple carburetor has an air entrance, a fuel nozzle and a float chamber fuel supply with two openings at the top, one connected to the same suction as the fuel nozzle and the other connected to a region of no suction, these connections having valves, *B* and *A* respectively, which can be opened or closed.

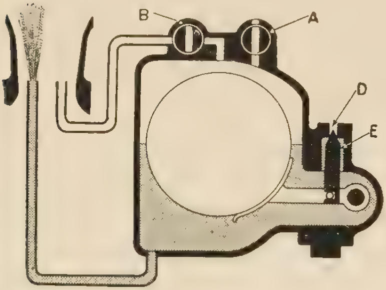


Fig. 71.

In Fig. 71, if the valve *B* be closed and the valve *A* wide open, there is the ordinary and usual condition of carburetor action, with suction on the jet, and no suction, but simply atmospheric pressure, on the float chamber. This condition exists when the mixture control is in the full rich position.

If, as shown in Fig. 72, the valve *B* were open and valve *A* closed, no fuel would discharge, because the suction being the same on either side of the metering jet, there would be no reason for the fuel to flow through it, and the fuel would simply take the level shown. There would, of course, be suction above the fuel in the float chamber, which would tend to draw more fuel through the needle opening *D*, but provided the float were sufficiently large, the valve *E* will hold shut and maintain the level in the float chamber at the normal height. This corresponds to the extreme "lean" condition that could be obtained with this type of control, in which there would be no fuel flowing at all. In actual construction, the suction connection is taken from a location of lower suction, as shown by the dotted lines in Fig. 73, so that with the valve *A* entirely shut, some fuel will flow. This condition usually corresponds to a correction of 30,000 feet altitude.

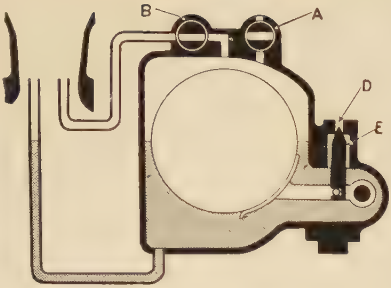


Fig. 72.

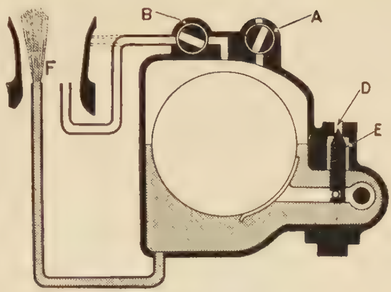


Fig. 73.

Fig. 73 shows how an intermediate condition may be obtained. If the cocks *A* and *B* be partially open, the pressure in the float chamber will not be equal to the full suction on the jet, nor will it be atmospheric pressure, but somewhere between, depending upon the relative openings at *A* and *B*. The rate of fuel discharge will consequently be between those of Fig. 71 and Fig. 72. And so long as *A* and *B* are left in one position, the pressure in the float chamber will always be the same percentage of the suction at *F* regardless of how the suction at *F* may vary, so that the action of any setting is uniform at all working speeds.

In these carburetors the desired range of control is so limited that the valve *B* may be dispensed with, a small hole of fixed size being used instead, while the total regulation is accomplished by motion of the valve *A*. In order that the action of the control be not sensitive, the closure of the valve must be rapid at first and then more gradual, and this is obtained by the use of a peculiarly shaped flat disc valve working upon an elongated opening or slot. (See Fig. 74.) The construction of the assembly is shown on Fig. 57. A spring performs the double function of holding the control valve to its seat and of producing enough friction to keep the altitude control lever

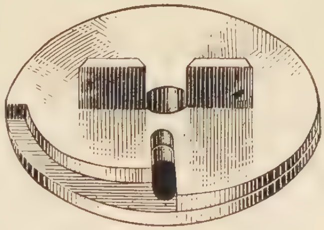


Fig. 74.—Altitude control disc and plate.

from vibrating. In all new models having this type of control, the control valve is made an integral part of the carburetor.

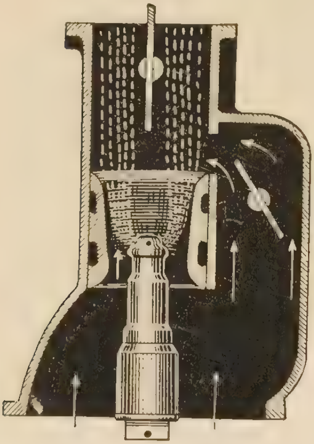


Fig. 75.—Airport type of altitude control.

Air Port Control.—The construction of the air port or auxiliary air type of control is shown in Fig. 75. As can be easily seen, this type of control operates to introduce air, which does not pass through the carburetor venturi tube, to the engine manifold. The air is taken from the carburetor inlet and enters the carburetor barrel just above the venturi tube. The effect of this is to lower the suction in the venturi tube. On some models a screen with vertical perforations is used to admit the air equally all around the carburetor barrel and also to permit fuel to drain down the intake passage without finding its way into the air port chamber, which might take place with low engine speeds at low altitudes when the air port valve is closed.

Combined Air Port and Float Suction Control.—On the NA–S4 carburetor for the Lawrence radial engines, a combination of the two types of controls has been used. The float vent, which determines the pressure existing in the float chamber, is located in the air port passageway on the atmospheric side of the valve. When the valve is closed, there is substantially atmospheric pressure in the float chamber; as the valve is opened, the velocity past the fuel jet and the suction thereon are reduced and at the same time a certain degree of suction, due to the air velocity through the air port passage, is placed on the float chamber. This method combines both types of controls and gives a gradual action, increases the air capacity at high speeds, and does not reduce the velocity past the jet to undesirable limits at high altitude.

"Automaticity" of Control.—It will be noted that all of the control methods mentioned preserve the automaticity of the mixture rang ; that is, any given setting of the control reduces the suction

on the jet by the same percentage at all engine speeds. Since the delivery of the jet bears a constant ratio to the suction, any given setting of the control has a substantially uniform effect upon the mixture at all engine speeds during which the main jet is in operation. Neither of these types of controls affects the idling jet operation.

Location of Float Chamber Atmospheric Vents.—The pressure of the propeller blast is often an appreciable percentage of the difference in pressures in the carburetor causing fuel flow and it is very important that whatever pressure disturbance is caused by the propeller blast should operate equally on both sides of the fuel metering jet, so that the fuel flow will be responsive only to the difference in pressures resulting from the flow of air through the carburetor. To insure this condition, the float vents and control openings, in all the types of controls referred to, are brought to the air entrance of the carburetor. Any pressure disturbance resulting from the propeller blast or forward motion of the ship is thereby balanced equally on the float chamber and on the fuel jet. Whatever slight depression may exist in the air entrance is transmitted to the float chamber and for this reason a manometer connected to the float chamber during dynamometer test may show some depression with either type of control in the full rich position.

The Double Models.—The double, or two-barrel, series of Stromberg carburetors include varied models, one having the float chamber to the rear of the two barrels, which are side by side, another in which the two barrels are separated by the float chamber whose center is approximately on a line between the centers of the barrels. Another type, the "Y," has the float chamber divided, part being in front and part in the rear of the two barrels which are side by side. There is also an inverted type with the float chamber in the rear, in which the air and mixture flow is downward through the carburetor.

CHAPTER X

IGNITION

THE gas mixture produced by the carburetor is of no value unless it is ignited, and, as said before, gas ignited quickly produces more force if first compressed. The gas mixture is sucked into the cylinder combustion chamber through the inlet valve as the piston travels downward. On the next upward stroke of the piston the two valves are closed and the gas is compressed. In what are termed "high compression" engines the compression is about eighty-five pounds to the square inch. When the gas is compressed an electric spark of great intensity is caused to jump from one spark plug point to the other, thus providing the means of igniting the gas. This firing of the gas mixture in the combustion chamber is called ignition.

Magneto Ignition.—The magneto as used for ignition purposes is a simple form of dynamo having its fields formed by permanent magnets and producing an alternating current of comparatively low voltage which is changed to a high tension current by means of an induction or transformer coil carried either in the magneto or as a separate unit.

The principle upon which a magneto of the armature type generates current may be understood by reference to Fig. 76. The parts shown at *A* include the horseshoe shaped permanent magnet *M*, to whose extremities are attached the extensions *P–P.*, called pole pieces. The inner faces of these pole pieces are curved and between them rotates the iron core *B* on the magneto drive shaft. On the core is carried a coil of wire *C* and it is in this wire that the current flow is induced. The coil and its core are parts of the magneto's armature.

With the armature in the position shown at *A* in the illustration the magnetic lines of force from the magnet poles flow from the positive to the negative side, taking the path indicated by the arrows

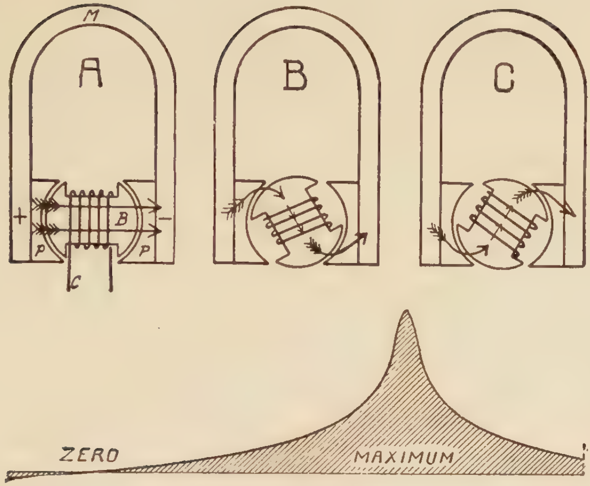


Fig. 76.—Principle of current generation in a magneto armature. Top: Armature positions. Bottom: Corresponding rise and fall of voltage.

through the center of the coil. As the magneto shaft is rotated, the core and coil finally assume the position shown at *B*. The lines of force still flow through the core, but because of the lessened surface presented to the face of the pole pieces, the flow has become smaller. Further rotation brings the parts to the position shown at *C*. Between *B* and *C*, the flow of magnetism through the coil stopped and again commenced, but now in the opposite direction through the core and the coil of wire. Between these last two points there has been an abrupt change in the intensity of magnetism acting on the coil, in fact a complete reversal has taken place, as the core once more assumes a midway position between the pole pieces, and for each complete revolution of the armature there are two abrupt changes of magnetic flow through the core and coil. The rise and fall of the voltage is shown by the curve in the lower part of the illustration.

A change of magnetism through the core of a coil would produce a flow of current through the coil. It will be seen as a result of this fact that there will be two separate flows or impulses induced in the coil for each full turn of the armature of the magneto. One of these

impulses is positive and the other negative in its direction of flow through the coil and connections, but for ignition purposes both are of equal value and each is used to produce an ignition spark or series of sparks depending on the method employed in the remainder of the equipment.

The action of the magneto is often explained according to the rate at which magnetic lines of force are cut by the wires of the coil or by the rate at which the magnetic lines of force are traveling relative to the coil wires. This method of explanation is the same in effect as the one just given, as will be seen by reference to Fig. 77. In the position shown at *A,* which corresponds to *A* in the pre-

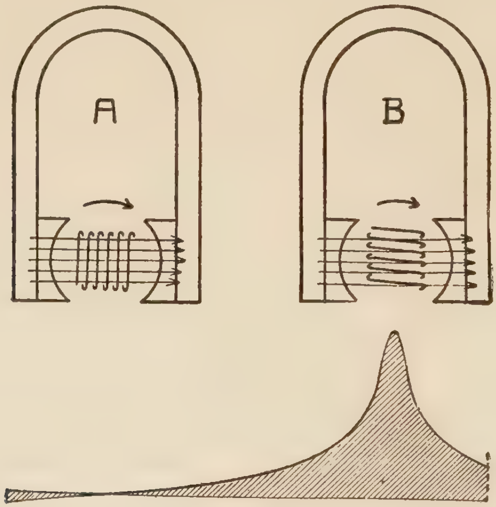


Fig. 77.—Magneto armature coil cutting lines of force in field. Top, armature positions. Bottom, change of voltage.

ceding figure, the lines of force pass through the coil as shown by the arrows and are cut through by the coil wires at the least rate of any point in the revolution. It is at this point that the current value is least, as will be realized from the preceding explanation, for the reason that this position is just halfway between the current impulses.

Again referring to Fig. 77 and position shown at *B*, it will be seen that the wires of the coil are cutting directly across the magnetic lines of force and therefore that the greatest possible number of lines are being cut in a given time. It is in this position, corresponding to the point between *B* and *C* of the preceding figure, that the current flow is greatest.

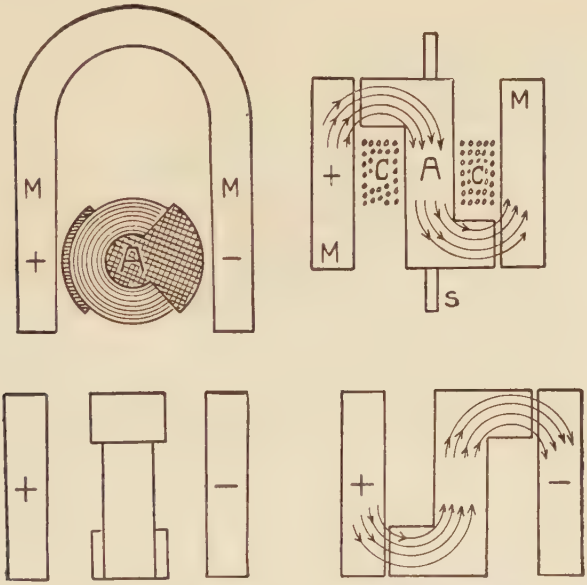


Fig. 78.—Principle of the inductor magneto.

Inductor Magnetos.—In the magnetos so far described, the coils of wire in which current is generated by the magnetic lines of force have been carried by a revolving armature in such a way that the intensity and direction of the magnetic flow changes during rotation, thus producing the electrical flow. There is another type of instrument used in large numbers with which the coils of wire remain stationary and with which the change in magnetic flow is secured by means of a revolving magnetic part, called an inductor.

The action of the inductor may be explained by reference to Fig.

78. The magnets M are of the U-shaped type and have their positive and negative poles on opposite sides of the rotating member, or inductor, which is carried on the driving shaft S. The inductor consists of a central cylindrical portion having extension pieces at each end, the piece at one end extending in one direction and that at the other extending the opposite direction away from the shaft. The inductor rotating member is made of laminated iron. Wound around the center of the cylindrical part of the inductor is the stationary coil C in which the current flow is induced.

With the magneto parts in the position shown at the upper right in Fig. 78, the flow of magnetism is from the positive to the negative magnet pole and passes downward through the coil winding. At the end of a quarter turn, in the lower left position, the inductor is in such a position that its extensions are midway between the magnet poles and the flow of lines of force has stopped and is ready to reverse. In the lower right diagram, one-half revolution from the position just above, the flow of magnetism through the center of the coil is again taking place, but now the lines of force pass upward or in the reverse direction from the first case. At the instant the magnetism changes, a powerful voltage is generated in the coil, just as with a wound armature machine. Continued rotation of the driving shaft and the inductor causes continued changes in the direction and intensity of the lines of force with resulting impulses of current flow in the coil winding.

Due to the fact that magnetos invariably require a speed of rotation not obtainable when cranking a large engine to start, a separate source of current is usually provided. This separate source of current is in the form of a small, high-tension magneto, called a *booster*, which is rotated by means of a hand crank, with the result that it sends a steady flow of high-tension current to the distributor of the main operating magneto. From here it is delivered to the cylinders in their proper firing order. When the engine starts the main magnetos function and carry on the work.

The Scintilla Aircraft Magneto.—The Scintilla is an inductor type of magneto, and instead of the conventional horseshoe magnets, one bell-shaped magnet is used, the rotation of which produces a reversal of magnetic flux through the core of the coil.

A brass end plate is fastened to the laminated pole extremities of

the rotating magnet. This plate carries the inner race for the rear-end ball bearing and the breaker cam.

The condenser is incorporated within the stationary coil and is located between the primary and secondary winding.

The contact breaker mechanism is held in position by a bayonet lock and can be completely removed, by hand, without the use of any tools.

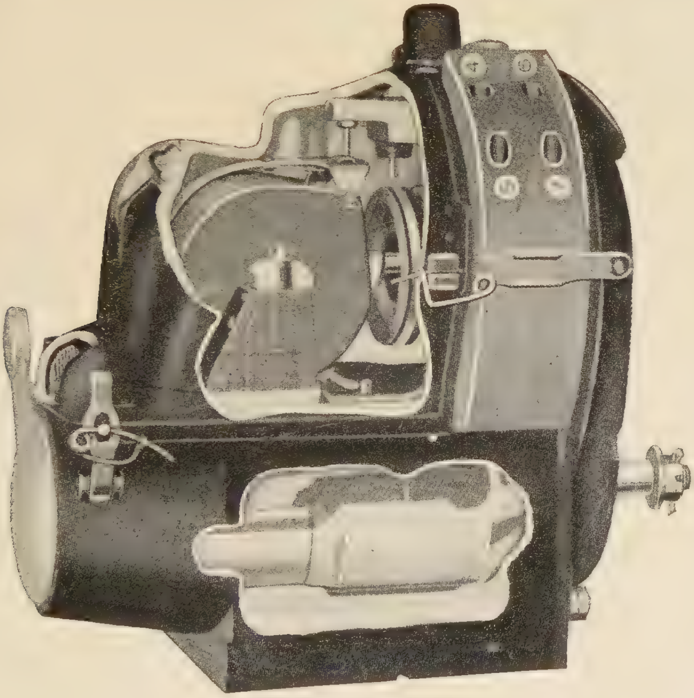


Fig. 79.—Cut-away view of the Scintilla aircraft magneto.

The internal construction of the Scintilla magneto is illustrated in Fig. 79.

Following is a description of the mechanical features of this magneto, illustrated by Fig. 80.

Magnetic Field and Contact Breaker.—The rotating magnet *1* has four poles. The poles are joined together inside the laminated

ends into pairs. The two N poles make up one pair and the other two, S poles, make up the other pair. The rotating magnet revolves between the laminated pole shoes, *2,* producing an alternating field in the core of the coil, *3.*

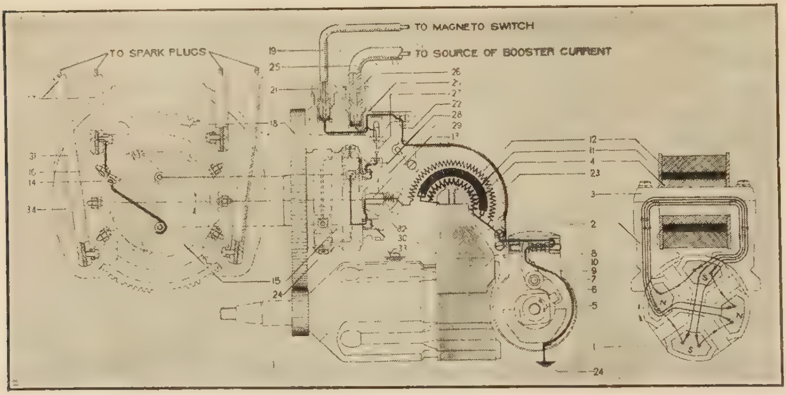


Fig. 80.—Parts of the Scintilla magneto.

1 *Rotating Magnet*
2 *Pole Shoes*
3 *Core of Coil*
4 *Primary Winding*
5 *Breaker Cam*
6 *Breaker Lever*
7 *Breaker Lever Axle*
8 *Long Contact Point (Insulated)*
9 *Main Spring for Breaker Lever*
10 *Short Contact Point*
11 *Condenser*
12 *Secondary Winding*
13 *High Tension Carbon Brush*
14 *Segment in Distributor Cylinder Carrying Secondary Current*
15 *Distributor Cylinder*
16 *Electrode in Distributor Block*
17 *Ignition Cable*
18 *Large Distributor Gear*
19 *Ground Wire*
20 *Booster and Ground Connection Block*
21 *Fastening Screw for Ground Wire*
22 *Stud for Ground Contact*
23 *Primary Bridge*
24 *Ground through the Magneto and Engine*
25 *Booster Cable*
26 *Fastening Screw for Booster Wire*
27 *Electrode for Booster Current*
28 *Collector Ring for Booster Current*
29 *Fastening Screw for Collector Ring (in Booster Circuit)*
30 *Fastening Screw for Collector Ring (in Secondary Circuit)*
31 *Segment in Distributor Cylinder Carrying Booster Current*
32 *Safety Gap Electrode*
33 *Ground Plate for Safety Gap*
34 *Distributor Block*

When the current reaches its maximum value, the breaker cam, *5,* causes the breaker lever, *6,* to turn on its axle, *7;* thus opening the platinum contact points, *8* and *10.*

The cam is mounted on the rear-end shaft of the rotating magnet, its position being fixed in relation to the magnetic field.

The short contact screw, *10,* is connected to the ground, *24,* through the breaker lever, *6,* and the main spring for breaker lever *9,*

while the long contact screw, *8*, screws into the insulated support and maintains permanent contact with the primary winding, *4*, by means of a laminated copper brush fastened on the primary bridge, *23*.

Therefore, when the contact points, *8* and *10*, are open, the primary circuit is suddenly interrupted.

Condenser.—The condenser, *11*, is connected in parallel with the contact points. It prevents abnormal arcing at the points when the primary circuit is interrupted, thus reducing their wear to a minimum and insuring regular sparking.

High-tension Current.—The interruption of the primary current induces a high-tension current in the secondary winding, *12*, composed of a large number of turns of fine wire. One end of the secondary winding is connected to the ground through the primary winding, *4*, and the core of the coil, *3*, while the other end terminates at the high-tension carbon brush holder which is built in as an integral part of the coil.

Distributor.—The high-tension carbon brush, *13*, transmits the current to the spark plugs through the medium of the distributor cylinder, *15*, and distributing blocks, *34*, and the ignition cables, *17*.

The high-tension brush bears on the central contact of the collector ring for booster current, *28*, which is secured to the distributor cylinder by two fastening screws, *29* and *30*. The screw, *30*, is located in the secondary current circuit and connects the central contact in the collector ring for booster current with the conductor molded into the distributor cylinder and leading to segment, *14*.

The distributor cylinder is fixed on the large distributor gear, *18*, in a definite position relative to the opening of the contact points and for a given rotation which, in the diagram, is anti-clockwise. Thus the segments, *14*, successively register with the electrodes, *16*, in the distributor blocks, thereby transmitting the secondary current to the ignition cables and thence to the spark plugs.

Safety Gap.—The safety gap is the space between the insulated electrode, *32*, which screws into the high-tension carbon brush holder, and the electrode, *33*, on the safety gap ground plate.

Its function is to protect the coil against excessively high voltage by providing a means of escape for the charge, which will jump the gap between the electrodes, *32* and *33*, in the event of the secondary circuit being accidently broken between the plugs and the coil.

Advance and Retard.—The advancing and retarding of the ignition time is obtained by moving the breaker assembly about the cam. Moving the breaker assembly against the direction of rotation of cam gives advance, while moving breaker assembly with direction of rotation gives retard.

Booster Connection for Starting.—The booster cable, *25*, is held by fastening screw, *26*. The booster current is carried to the electrode for booster current, *27*, through the medium of a conductor molded into the dielectric material of the booster and ground connection block, *20*, thence through a small air gap to the collector ring for booster current, *28*. The fastening screw for the collector ring, *29*, is located in the booster current circuit, transmits the booster current to the segment, *31*, in the distributor cylinder. The booster current then jumps the air gap to the nearest electrode in the distributor block and thence through the ignition cable to the spark plug.

The booster current segment is located in such a manner that it trails the secondary current segment, *14*.

Stopping the Engine.—To stop the engine, the ignition is cut out by neutralizing the functioning of the contact points. This is accomplished as follows: The end of the primary winding, *4*, terminates through the spring contact on top of the primary bridge, *23*, and thence through the stud for ground contact, *22*, to the primary terminal, marked *P*, and carrying the fastening screw for ground wire, *21*. The ground wire, *19*, goes to a switch located conveniently for the pilot.

When the switch is closed, the effect of the contact points is neutralized by permitting the primary current to flow around the points and through the switch to the ground, thus grounding the primary current and causing the ignition to the engine to cease.

Parts of the Magneto.—The Scintilla aircraft magneto, when disassembled for inspection or repair, consists of the following subassemblies:

1. The rotating magnet.
2. The contact breaker.
3. The front end plate.
4. The coil.
5. The magneto housing.

6. The main cover with booster and ground connection block.
7. The distributor blocks.
8. The breaker cover.

The Rotating Magnet.—The rotating magnet is supported in the magneto housing by the drive end bearing and the breaker-end bearing. End play is adjusted by spacing washers behind each inner ball race. The drive end shaft carries the inner race for the drive-end bearing and the small distributor gear which is keyed to the drive end shaft. The breaker-end shaft carries the inner race for the breaker-end bearing and the breaker cam. The breaker cam is keyed on a taper shaft and secured by a screw.

The Contact Breaker Assembly.—The contact breaker assembly mechanism is carried by the breaker cage. The breaker cage has its ground and compensating springs riveted to it. It carries the breaker lever and its axle and the short contact screw. The insulated support carrying the long contact screw and fiber stop is mounted at the top of the breaker case. The flat spiral bayonet-lock spring lies between the back of the breaker cage and the dog plate and inside the bayonet-lock latch. The oil wick for the cam is located in the bottom of the breaker cage. The main spring for the contact breaker lever has a short reënforcing spring under the breaker lever end and a long reënforcing spring under the breaker cage end. It is fastened by a screw at each end. The end cover with advance lever is held solidly against the back of the contact breaker assembly by a screw which seats in the breaker cage and screws into the centrally located boss in the end cover. There are two dogs, 180° apart, which fix the position of the advance lever by engaging in holes in the dog plate. The advance lever may be fixed and held in any one of eight positions.

The Front End Plate.—The front end plate is fastened to the main housing by two studs in the bottom holes and two screws in the upper holes. Its position is fixed by two dowel pins in the front end of the magneto housing.

The front end plate holds the outer ball race for the drive-end bearing. It also carries the large distributor gear and distributor cylinder upon the distributor gear axle. The distributor gear axle is fastened to the end plate by two screws. The distributor gear is locked on its axle by a steel spring ring which seats in an annular

groove in the end of the axle. The steel spacing washer between the back end of the distributor gear bearing and the spring ring on the axle provides a means of adjustment for the end play of the bearing. The distributor cylinder is locked to the distributor gear by a spring ring. The correct position of the distributor cylinder for a given rotation is fixed by a dog screw, which screws into the distributor gear. The spacing of the distributor cylinder from the gear by a large paper washer assures a tight fit for the spring ring against the distributor cylinder when the ring is pressed into its groove in the distributor gear. The front end plate also carries the distributor block spring clamps.

The Coil.—The coil is mounted directly on the extensions of the laminated pole shoes, thus insuring the coil a maximum freedom from oil and grease, as this mounting puts it well up under the main cover. The pole shoe extensions are grounded to insure a good contact with the core of the coil. The coil is held in place by a screw in each end of the core.

The condenser is built in as an integral part of the coil. This assures protection for the condenser and a practically uniform capacity irrespective of temperature and moisture. The high-tension carbon brush holder and safety gap electrode are mounted on the front of the coil. The ground connection and the spring contact for the insulated support of the stationary contact point are incorporated in the primary bridge which extends over the top of the coil and is secured by six small screws.

The Magneto Housing.—The magneto housing covers the rotating magnet. It carries the outer race for the breaker-end bearing, the ground plate for the safety gap, the breaker cover spring clamps and the dowel pins for locating the main cover and breaker cover. The pole shoes are laminated and cast as an integral part of the magneto housing. The breaker stop and its fastening screws are located in the lower part of the breaker end of the magneto housing.

The Main Cover with Booster and Ground Connection Block.—The main cover is located by four dowel pins and is fastened to the magneto housing by two screws. It affords protection to the coil from moisture, oil and dirt under abnormally severe operating conditions.

The booster and ground connection block is mounted in the

extension of the main cover between the distributor blocks. It is secured in position by two screws.

The booster and ground connection block carries the ground terminal and the stud for ground contact, also the booster terminal and the electrode for the booster current. The stud for the ground contact bears on a spring plate secured to the primary bridge. The electrode for the booster current is held directly over the collector ring for the booster current. There is a small air gap between the electrode and the collector ring.

At the top of the main cover are provided numbers for locating the distributor blocks, an arrow showing the direction of rotation of the magneto and the two letters *H* and *P* to mark the booster and ground terminals respectively.

The Distributor Blocks.—The distributor blocks are mounted so that they are held between the main cover and the front end plate. Their lower ends rest upon the magneto housing while the upper ends fit against the top extension of the main cover. They are held in place by spring clamps and are designed as the right and left distributor block as viewed from the drive end.

The Breaker Cover.—The breaker cover is located on the magneto housing by two dowel pins and held in place by a spring clamp at each end. It is directly over the contact points and its removal permits of a ready inspection of the points or removal of the contact breaker assembly.

How to Dismantle the Magneto:

(1) Remove the safety pins on breaker cover and distributor block spring clamps.

(2) Release spring clamps and remove breaker cover by lifting straight up.

(3) Remove breaker assembly. This is easily done by moving the breaker to midway between advance and retard positions. Now bring the bayonet-lock hand latch to a vertical position; this unlocks the bayonet lock and the breaker assembly is then easily removed by pulling outward.

(4) Release spring clamps and remove distributor blocks.

(5) Unscrew fastening screws for magneto cover and remove it by lifting straight up until the cover clears the coil. Should the cover be tight on the dowel pins it can be loosened by alternately tap-

ping it with a fiber drift on the rear edge just over the breaker compartment and lifting the front by hand.

(6) Unscrew fastening screw in each end of core of coil and remove coil by pulling it back until the high-tension brush clears the distributor cylinder; then lift coil out. Care should be exercised in removing the coil. Do not pull straight up on it until the high-tension brush clears the face of the distributor cylinder. Some coils fit fairly tight between the pole shoe extensions and when they release themselves under a vertical pull, will do so quite suddenly and the high-tension brush will be broken and possibly its holder torn loose from the coil; hence the warning—move coil back until the high-tension brush clears the face of the distributor cylinder, then it may be lifted out.

(7) Remove the two fastening screws and the two nuts and lock washers from each of the bottom studs, then pull the front end plate off. If the end plate should fit tight it may be loosened by alternately tapping it gently on each side of the inside surface with a rawhide mallet.

(8) Remove the rotating magnet. This is done by turning the rotating magnet until an opening between any two poles of the magnet appear in the center between the top edges of the pole shoes. This allows the flat surfaces of the magnet to be in such a position that the rotating magnet can be readily withdrawn from the housing.

(9) Take the distributor cylinder off the large distributor gear by releasing the spring ring that holds it. There is a recess in the outer edge of the distributor cylinder flange for the ends of the spring ring. The ring may be released by prying with a small screw driver between the flat part of the ring and the inside of the distributor gear, thus forcing the end in far enough to clear the groove cut for it. When the ring is released the distributor cylinder may be lifted off.

(10) Remove large distributor gear by first releasing the small steel spring ring, then removing the spacing washers and lifting gear off the axle shaft.

(11) Remove the end cover with advance lever from breaker assembly by unscrewing the fastening screw in back of breaker cage.

Cleaning the Magneto.—All parts of the magneto may be washed in gasoline and dried with compressed air except the coil. Wipe all pieces of dielectric material, insulation in other words, with an oil-saturated cloth after cleaning.

There are several precautions to be observed in drying off the parts. The number discs on the distributor blocks and those on the top of the main cover must not be exposed to full air pressure. Hold them at a safe distance or else allow them to dry in the open air. Great care should be taken that the felt strips in the magneto housing, the main cover, the breaker cover and the front end plate are not loosened or torn out by the air pressure.

Oil all felt strips after cleaning.

It is important that the cage and bearing assembly of each bearing should be held so that they cannot spin while using air for cleaning. This will prevent throwing out the balls and making it necessary to obtain a new cage and ball assembly to complete the bearing for reassembly.

Keep the rotating magnet clean inside and out. Do not lay it near small screws, nuts or metal chips, etc. Its construction is such that any foreign material adhering to it will result in serious injury to the magneto. After cleaning the rotating magnet, grease it thoroughly to prevent rust.

Reassembling the Magneto.—It is presumed that the workman will, as far as possible, use the original parts of the same magneto when putting it back together.

While Scintilla magneto parts are readily interchangeable in each type of magneto and for a given rotation will function in another magneto of the same rotation, much time and effort will be saved by using the same rotating magnet, magneto housing and front end plate in the reassembly.

The end play and bearing fit of the rotor in the magneto in most instances will be found to be correct.

The rotating magnet was taken as the last sub-assembly for inspection so that while it was cleaned up it could be installed in the magneto housing immediately.

(1) Have the magneto housing clean and ready to receive the rotating magnet.

(2) Take up the rotating magnet and fill the rear ball cage with good light grease. Grease magnet all over, leaving a film of grease to prevent rust.

(3) Recharge rotating magnet, clean off metal particles that may be adhering to poles and place in the housing at once. The magnet

is easily replaced by turning it until a flat surface is at the top, then push into place. Now, turn the rotating magnet right or left 45° or until the space between the top of the pole shoes is filled by one of the poles of the magnet. This is the neutral position for the rotating magnet and it should always be left in this position unless there is a keeper across the pole shoe extensions.

(4) Fill the cage and ball assembly for front bearing with the light grease mentioned before. Put it on over the shaft and place it on the inner race. Note: If the magneto is an AG 12–D type the cage and ball assembly must be placed in outer race in front end plate and assembled with it.

(5) Observe the arrow on top of the main cover to find the direction of rotation for which internal timing was originally set. If arrow points anti-clockwise, as viewed from the drive end of the magnet, match all timing marks G. If arrow points clockwise match all timing marks D. Suppose the magneto to be assembled is an anti-clockwise or of left hand rotation:

(6.) Turn rotating magnet until the marked tooth on back of small distributor gear is up in view so that it may be matched with the marked tooth on the large distributor gear.

(7) Take up front end plate and put it on over drive end shaft until edges of gears are about to touch, holding the plate in one hand and guide the mark on the large distributor gear by turning the distributor cylinder with the other hand. When the marked tooth on the small gear and the marked tooth on the large distributor gear are matched, push the front end plate up against the magneto housing and secure by means of the two screws and studs provided.

(8) Test rotating magnet for end play. There should be none. The bearings should be just tight enough that when the magnet is turned about 30° from the neutral position it will return to the neutral position by its own magnetic pull.

(9) Replace breaker assembly for final setting. Set contact points so that their maximum opening will be .012 of an inch. The small gauge on the special contact point adjusting wrench furnished with these magnetos may be used for this purpose.

When the contact points are set at .012-inch for maximum opening the clearance between the back of the breaker arm and the face of the fiber stop should be from .002 to .010-inch. Also check the clearance on each cam lobe. The cam must run true within .0005 of an inch.

(10) The internal timing of the magneto must now be checked.

Turn rotating magnet until the figure 1 on the large distributor gear is in line with the mark in the timing window; the supplemental timing marks, located on the inside edges of the large distributor gear and the front end plate, should also be in line at this time.

By slowly rocking rotating magnet with the breaker in the full advance position, the points should be just on the instant of opening as number 1 and its mark and the supplemental timing marks come in line with each other. Hold rotating magnet with timing marks in line and with one hand place the right distributor block in position. When the magneto is correctly timed, the number 1 electrode will coincide with a segment on the distributor cylinder.

(11) Remove the breaker assembly; this allows an easier installation of the coil.

(12) Place coil between pole shoe extremities. This is best accomplished by sliding coil in from the back and moving it forward into position. The coil fits tight and often causes the pole shoe extensions to shear off a very thin piece of the fiber side plate. Take every precaution that none of this fiber gets in between the ends of the core of the coil and the ends of the pole shoe extensions. Secure coil with a fastening screw in each end of the core.

(13) Replace breaker assembly. Spin magneto. If properly assembled and timed a good snappy blue spark will jump across the safety gap. The safety gap should be not less than three-eighths or more than one-half of an inch.

(14) Put main cover in place. Take great care that it fits the housing easily. Have the bottom edges of the main cover smooth. It is important that the cover fits the housing accurately since the top extension of the cover acts as a stop for the distributor blocks while the housing supports them at their lower end. Any serious misalignment would result in injury to the electrodes in the distributor blocks and segments in the distributor cylinder. Fasten the main cover to the housing with the two long screws provided.

(15) Replace the breaker cover. Fasten the spring clamps and safety them.

(16) Replace the distributor blocks. Match them up with the number discs on the sides of the top of the main cover. Fasten the distributor block spring clamps in place and safety them.

Periodical Inspection of the Magneto.—See that the breaker stop and the safety gap ground plate is tight and that the fastening screws are locked. Have the ⅜-inch cap-screw hold-down holes

clean and the threads straight. Lap the base just enough to make sure the surface is smooth. It is essential that the oil lead to the back bearing be open and clean. It should be flushed with a good grade of light oil after cleaning.

Lift the oil wick and spring out of the distributor gear axle. Clean the oil leads to the axle and front end bearing then flush with a good grade of light oil. Replace the oil wick in the distributor gear axle. See that the fastening screws for the distributor gear axle are tight and locked to the outside surface of the front end plate.

Examine the large distributor gear to see that there are no burrs on the gear teeth. Replace the gear, taking care to hold the wick down until covered by gear bearing. Replace the spacing washers and spring ring. Try the end play of the gear on its shaft. If not less than .005-inch or more than .008-inch, it is satisfactory. Test the dog screw; it must be tight and locked to the large distributor gear.

Replace the paper spacing washer and distributor cylinder, also the spring ring. The total thickness of spacing washer should be such that the distributor cylinder will be held tightly against the distributor gear. Force the spring ring into its groove throughout its length.

Replace the end cover with the advance lever on the breaker assembly. Place the assembly in position in the magneto housing and note that it functions as follows:

The bayonet-lock latch, when released, should snap into position and the breaker will spring over to full advance. Remove the breaker and lay aside for adjustment during final reassembling.

Clean the oil lead to the back bearing thoroughly. Examine booster and ground connection block in top of main cover, especially around the terminal marked *H*, as any small cracks in the material would ground the booster current.

Note that the secondary brush holder is solid with the coil. It is of vital importance that the spring contacts on the primary bridge be in good condition. The rear spring bears against the face of the insulated support on top of the breaker cage, while the front spring located above the coil makes contact with the ground contact stud.

Examine the electrodes, be sure that they are screwed tight into

the distributor block. Loose number discs must be glued with a water-and-oil-proof glue. After the glue is dry, apply white shellac as an added precaution.

Check the cam fastening screw. Note condition of ball bearings. It will be noticed that the cage and balls of the front bearing are a loose part on the AG 12–D rotating magnet, while on the AG 8–D and AG 9–D rotating magnets they stay on the inner race. This allows the balls to clear the large distributor gear during the assembly of the AG 12–D. All types of rotating magnets carry the cage and balls for the rear bearing on the inner race.

Examine the laminated pole end of magnet for any signs of rubbing due to foreign material lodging between laminated ends of magnet and pole shoes. The clearance between the laminated poles and the pole shoes should be .002-inch. This explains the necessity of keeping them clean and free from any foreign material.

Testing Magneto.—Where test-bench equipment is available, the magneto should be tested immediately after assembly. Its operation during a bench test gives the experienced mechanic an accurate check on the mechanical and electrical condition of the magneto.

Mount the magneto on the test bench and remove the breaker assembly. Run the magneto up to about 1,000 revolutions per minute and listen carefully to its running.

The period of any unusual or irregular noise as compared with drive shaft speed will give a good indication as to its origin.

While listening to the magneto, note the hum of the gears. When running properly they will have a consistent hum. The pitch of this hum will vary slightly for different magnetos, but will be consistent for a given magneto when the gears are running properly.

When there is foreign material imbedded in the face of the large gear, it will cause an audible click or knock each time it is turned against the small distributor gear.

When foreign material is imbedded in the face of the small distributor gear, the period of the knock will be that of the drive shaft rotation, since the small gear is keyed to the drive shaft.

Should the gears run irregularly and tend to chatter, there is excessive play either in the distributor gear axle bearing or between the teeth of the gears.

If there is a knock in the magneto housing it is usually caused by the laminated poles hitting the pole shoes.

Most trouble in the magneto housing is caused by small metal parts, such as filings, chips, broken lock washers, etc., that are picked up while the rotating magnet is on the bench. They are thrown out by centrifugal force and cause serious damage to the rotating magnet and pole shoes.

Unusual tightness or rubbing in the housing may be noticed by the magneto running exceptionally warm during the test. If the condition is bad it will be noticed by an irregular and unusually hard turning when the drive shaft is turned by hand prior to the test run.

Replace the breaker assembly and wire up distributor blocks to the spark gap, which should be of the three-electrode type in order to obtain good and consistent results for testing. The third electrode is a static point located so that it meets the live point at an angle of 90° and is set with an air gap of about .002-inch between static point and live point. The live point is the one connected to the distributor block by the high-tension cable. The gap between the live point and the grounded point should be 9/32 of an inch. Keep all points sharp and clean to obtain the best results.

Run the magneto for about ten minutes at a speed 900 to 1,000 revolutions per minute. Observe the points at the start of the test. Should they arc excessively, remove the breaker and clean them thoroughly. Have points dry and free from grease before replacing the breaker.

After ten minutes at above speed, run the magneto up to 2,800 revolutions per minute and maintain this speed for at least five minutes. Observe the breaker contact points. There should be very little sparking when they are clean, and seat properly on their contact area. If they still arc excessively it is very likely that the condenser is at fault and should be replaced.

Test the primary grounding circuit with a piece of wire. Put one end in the hole in fastening screw for ground wire and touch the other end of the magnetic body or frame of the test bench. The spark across the gap should cease the instant the free end of the grounding wire is touched to the magneto or test-stand frame.

The next running speed should be not less than 3,500 revolu-

tions per minute while 4,000 is better. Maintain this speed for at least ten minutes. Observe the spark closely. A consistent miss can be readily detected. A slight scattering miss will be detected by a momentary break in the spark flame between the electrodes. A magneto, the internal timing and assembly of which is correct, will regularly fire across a 9/32-inch air gap at 4,000 revolutions per minute. The contact points should run practically free from arcing by now.

The test following the high-speed test should be that for coming-in speed. The coming-in speed is the lowest speed at which the magneto will come in and fire consistently across the 9/32-inch air gap. The maximum coming-in speed allowed for full advance is 120 revolutions per minute, while that for full retard is 240 revolutions per minute. Coming-in speeds higher than these would indicate a magneto of low electrical efficiency. This may be due to improper internal timing or to the rotor having lost some of its magnetism through improper handling, after being recharged, or by spinning the rotating magnet without a keeper across the pole shoe extensions.

The booster starting circuit should be tested after the finish of the running tests. Use a hand magneto or a vibrating high-tension coil as a source of high-tension current. Connect the high-tension booster current cable to the terminal marked *H*. Rotate the magneto by hand. Start with Number 1 in the timing window and observe that a spark jumps all gaps in the correct serial order as given by numbers on the distributor blocks. Bear in mind that because the booster segment trails the service segment of the distributor cylinder, the booster spark will occur later. For example, when Number 1 shows in the timing window, the booster current will jump Number 12 gap. The same principle applies to the eight- and nine-cylinder magnetos.

A deviation from this serial order, or no spark at all across the gap, indicates that the booster circuit is not correct. Examine the parts for fine cracks or burned spots, indicating a short circuit of the booster current.

Installing the Magneto and Timing to Engine.—Make sure that the magneto shaft half of the drive coupling is seated and keyed on taper of drive shaft and then locked by nut and washer, also

safetied with a cotter pin. Spin the magneto and note that drive shaft half of coupling runs true.

Inspect the magneto base. See that the 3/8-inch threads in the hold-down holes have not been stripped or that the start of the thread has not been closed; thus causing the cap screw to start cross threaded. When necessary clean up threads with a tap of proper thread and clean out holes thoroughly.

The dowel pins should fit snugly the holes provided for them, but not so tight that it is difficult to get the magneto down on the surface of its support. Make sure that the magneto base is smooth and makes good contact with the bracket surface.

It is important that the 3/8-inch hold-down cap screws be of the proper length; when in doubt, measure. Make allowance for the thickness of the washer used on the screw. The cap screw length must be such that, when the screw is tight, it will not have less than 7/16-inch or more than 1/2-inch of its threaded length in the hole in the base of the magneto. When this has been corrected, draw the cap screws tight and safety.

Timing.—Turn the engine slowly as piston in cylinder number 1 comes up on compression. Stop turning when the full advance position for the ignition, as given by the manufacturer, is reached. This point is given in degrees before top center, (B.T.C.) and is marked on the timing disc to be used with the particular engine. At this point the magneto is to be coupled to the engine, following the instructions below.

The Number 1 on the large distributor gear can be seen through the timing window located under the front oil-hole cover. When this Number 1 is in line with the white mark at the top of the timing window, it indicates that the contact points are at the instant of opening with the breaker fully advanced and the Number 1 electrode on the distributor block is registering with the proper segment on the distributor cylinder.

Some installations do not permit of the timing window being used. In such cases the supplemental timing marks must be used. They are located on the inside surfaces of the large distributor gear and the front end plate. They are so arranged that, when they coincide with one another, the contact points are at instant of opening.

Next fasten the spark plug cables to the distributor blocks. The numbers on the distributor blocks show the serial firing order of the magneto. The numbers on top of the main cover are for the purpose of locating the right and left distributor blocks to their respective sides.

Make sure that each magneto is wired to its proper set of spark plug wires as given by the engine manufacturer. Also make sure that the wires lead from the magneto so that number 1 on the distributor block goes to Number 1, or the first cylinder to fire, while number 2 on the distributor block goes to the second cylinder to fire, and so on with the other wires until all the cylinders have been wired in their proper firing order. Then clamp the distributor blocks in place.

The letter *H* marks the terminal to which the booster wire is to be connected.

The letter *P* marks the terminal to which the ground or short circuiting wire from the magneto switch is to be connected.

The arrow indicates the direction of rotation of the magneto when viewed from the drive end.

Tighten and lock the drive coupling. The advance lever linkage is to be connected to the advance lever on the magneto, special attention being given that full advance and retard are obtained when the spark lever in the cockpit is moved to its full advance and retard positions.

Adjusting End Play of Rotating Magnet.—As there is only .002-inch air gap between the rotating magnet and the pole shoes, and in consideration of the design of the ball bearings, it is important that there be a very careful adjustment of the end play of the rotating magnet between its bearings.

Since the rotating magnet exerts a certain amount of attraction between its poles and the pole shoes, when turned from the neutral position, advantage is taken of this pull to get the correct adjustment of the ball bearings. The end play adjustment is really carried beyond the point where a mechanic could actually feel even the slightest hint of end play.

The correct adjustment is observed by turning the rotating magnet away from its neutral position and noting how far the trailing edge of the rotor slot can be from the edge of the opening between

the pole shoes and still return to its neutral position. Obviously, the closer the edge of the slot must be to the pole shoe edge in order to pull back to neutral, the tighter the bearings. It has been found in practice that when the distance between the pole shoe edge and the rotor slot edge is from 3/8-inch to 3/4-inch, the adjustment is satisfactory, while 5/8-inch is the desirable adjustment.

The adjustment of the end play is obtained by means of steel spacing washers which fit in between the inner ball races and the rotating magnet. Keep the total thickness of spacing washers just as nearly equal as possible on each end. These spacing washers come in thickness of .05, .1, .2, .3, .4 and .5 of a millimeter, which is approximately .002, .004, .008, .012, .016 and .020 of an inch respectively.

Contact Points.—The life of the contact point depends a great deal on how clean they are kept. File them only when it becomes absolutely necessary for the best operation of the magneto. The gap between the contact points, when fully opened, should be maintained at .012-inch.

Adjusting Fiber Stop.—The fiber stop is mounted in the insulated support just back of the top of the breaker lever. Its function is to limit the travel of the breaker lever at high magneto speeds. The fiber stop clearance is measured between the face of the stop and the back of the breaker lever. The clearance must be measured with the points fully opened, and should not be less than .002-inch. This may be obtained in a practical way by using a .002-inch feeler gauge, placing it behind the breaker lever and turning the rotating magnet until the points are at their greatest opening.

Care should be taken in filing the fiber stop so that when the proper clearance is obtained and the breaker lever is pushed back against the stop, the whole surface of the stop bears against the back of the breaker lever.

It is not practical to state a maxmium fiber stop clearance which could be applied to all Scintilla magnetos, because the fiber stops and cam followers together with the contact points do not wear exactly alike.

Oiling the Magneto.—Proper lubrication is of vital importance

for the satisfactory operation of the magneto. Use the best grade of medium-bodied oil obtainable.

Put from thirty to forty drops of oil in the front oil holes, or until it appears at the overflow hole, for the distributor gear axle bearing. This hole is located about one inch below the front oil-hole cover.

Put three to five drops of oil in the back oil hole.

Be sure that the felt wick in the bottom of the breaker cage is thoroughly saturated with a heavy-bodied oil.

Oil the magneto at regular intervals after each ten hours of engine operation.

CHAPTER XI

PROPELLERS

THE airplane propeller is an all-important part that converts the energy of the engine into thrust, and thus propels the machine through the air. The propeller is quite complicated in its correct design and one of the least understood parts as to direct results obtainable from a particular shape. The propeller shape must be such that the power developed by the motor can revolve it at sufficient speed to produce thrust equal to, or greater than, the total drag, or resistance, of the airplane.

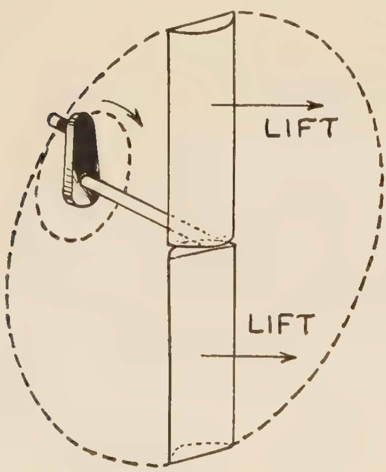


Fig. 81.—Principle of propeller action.

A propeller blade might be likened to an airfoil; it is shaped to perform the same function and obtain a similar result. It is cambered to the proper shape and propelled through air at high velocity. To make a simple illustration, imagine two small wings placed end to end with the leading edge of one on a line with the trailing edge of the other, as shown in Fig. 81. Imagine these wing sections mounted on a shaft at the point where they join. As the shaft is revolved one section travels in the opposite direction to the other, but in passing through the air both exert a lift. The lift, instead of being exerted in a vertical plane, is exerted horizontally and called *thrust*. This is the basic principle of a propeller.

Such a symmetrical shape as these two wing sections would be

totally unsuited for a practical propeller because that part of them farthest away from the shaft revolves at a far greater speed than that part near the shaft and would exert too great a lift on the outer parts. This would result in placing all the work on the tips and leave the center part as dead weight not revolving at sufficient speed to provide any efficiency. The angle of the propeller blades in relation to the hub is in reality an angle of attack, and is, therefore, reduced as the speed is increased, or near the tips. If this were not done the tips would exert a thrust out of proportion to the rest of the blade. For this reason the angle, or pitch, as it is called, is made greatest at the hub, the point of least velocity, and gradually diminished toward the tips. This results in the thrust load being distributed as evenly as possible over the whole blade area. A typical example of this is illustrated in Fig. 82.

Fig. 82.—Blade and shape at various points.

The exact reaction of air to propeller pitch is mathematically complicated and for this reason only the most elementary features will be explained here.

A propeller is sometimes called an "air screw" for the reason that it travels forward as it revolves in much the same manner as a screw bolt travels forward through a nut. The propeller blade tips travel through the air in a curve called a helix somewhat the shape of a huge screw-thread curve. When a bolt is screwed into a nut it advances a certain distance each complete turn, this distance being called the pitch of the threads. The pitch of a thread is measured as the distance between two adjacent threads. Propeller

blades are bent so as to scoop air toward it, the angle of this bend being called the propeller pitch. The pitch of a propeller is measured in the same manner as that of a bolt, the distance it would travel through the air in one complete revolution if the air were solid.

But since the propeller operates in a fluid, air, there is a certain amount of loss; the propeller cannot advance a distance equal to its pitch. The difference between the distance the blades would travel if the air were solid and the distance it actually travels is called the *slip*. In order to provide sufficient thrust the angle of the blades, or the pitch, must be the amount of slip greater than the angle of the effective helix.

The pitch is determined by the angle of the blades. This angle is measured from the chord of the rear face to a line directly at right angle to the propeller shaft, which is the plane of propeller rotation.

The rear face of the blade is invariably flat while the front face is cambered like a wing section. Just as there is a speed below which a wing section exerts no lift, so there is a propeller blade speed below which no thrust is exerted and this low speed occurs at points at and for some distance out from the hub. In fact, the greatest amount of work is applied to the outer third of the blade, the inner third performing practically no work and only churning up the air uselessly. Blade camber is very important as related to the propeller's efficiency, being thickest at a point about one-third of the chord from the leading edge. The middle third of the blade is where the work commences to be applied. It is for this reason that the inner third and the hub of most propellers are covered with a streamline hood called a spinner which deflects the wind and reduces drag.

Another reason for the decrease in pitch and the increase in thickness of the blades near the hub is to supply the strength necessary to hold the blades from flying apart under the tremendous centrifugal force exerted on them when revolving at say 1,800 revolutions per minute.

If the pitch is not carefully calculated, uneven loading will result and consequent blade distortion. In case too great an amount of

thrust is placed on the blade tip it is liable to break or at least flutter and cause excessive vibration.

As the blades strike the air they impart added velocity to it and sweep it backward. This is called the propeller slip-stream. The air is churned at the same time in much the same manner as water being thrust backward from a boat propeller is churned. This disturbance continues for some time and distance back of the plane and is called the wash of the propeller.

The larger the diameter of the propeller up to a certain point, the more efficient it is, therefore the diameter should be the greatest that can safely be swung on the plane. The larger the propeller the slower it revolves, due to the horsepower required, but the large, slowly revolving propellers are far more efficient for pulling ability than are the smaller, high-speed type. Accelerating a large mass of air slowly with a large diameter propeller is much more economical than to accelerate a small mass of air to great velocity with a smaller one. The greatest permissible diameter is, of course, governed by the power plant, height of chassis with consequent propeller clearance, and many other things. It is possible to calculate the required pitch and diameter fairly accurately for any given horsepower and load and this is done keeping in mind the greatest dimensions possible and still allow the engine to turn over at its most efficient number of revolutions. If a propeller is of too great a diameter and is of too great a pitch the motor cannot revolve it at an efficient speed, which is usually between 1,500 and 1,800 r.p.m.

The two-bladed propeller has been found to be the most efficient, three and four blades being used only when the diameter is limited by the design of the airplane. If there is not sufficient room for a large propeller to revolve in the clear the diameter is reduced and more blades used. In propellers having more than two blades, however, they follow each other too closely and operate in disturbed air that has not had a chance to clear from the preceding blade.

Until lately all airplane propellers were made of wood: ash, birch, mahogany, walnut, maple and white oak. Spruce was found suitable for power plants up to fifty horsepower, being light and strong enough to carry this power. European designers use mostly mahogany and walnut, although they are very expensive. On engines under 125 horsepower, birch, being comparatively light for its

strength, is very satisfactory. Ash has the objectionable feature of being unable to withstand moisture and consequent warping, although very strong, fibrous and light. Maple is altogether too heavy for its strength as compared to other woods. Quarter-sawed white oak is the best all-around wood for propeller construction, even though it is rather difficult to work and glue. It is exceptionally strong and hard for its weight and is used on the largest engines.

Wooden propellers are built up of sections, or laminated, usually starting with one-inch planks which are finally dressed down to around three-quarters of an inch. After the surfaces are roughened by a tooth plane they are coated with hide glue, heated to 140° F. From five to ten planks, or laminations, are then piled one on top of the other and held pressed together by clamps or a press for about eighteen hours, or until the glue has thoroughly set. The gluing and pressing of the planks must be done in a room whose temperature is 100° F. The temperature of the glue, when applied, and the temperature of the room and wood is very important and should not vary from those stated.

The propeller is then roughed to approximate shape and allowed to stand about ten days so that all the glue stresses are adjusted to the wood. If they are not allowed to set for this length of time the propeller is liable to warp out of shape. After this period the propeller is again worked down to within a fraction of its finished shape and size and again allowed to stand for a few days, after which it is finished to exact shape by hand scraping. It is then tested for track, pitch, hub dimensions and balance. The balance is very important and great care is taken that one blade is not the least bit heavier than the other. If this were the case a varying side thrust would be exerted on the engine bearing causing damage and excessive vibration.

The propeller is then finished to a glossy, glass-like surface by using either several coats of spar varnish or by rubbing in several coats of hot linseed oil. Linseed oil dressing requires about five coats. The wood should never be touched with sandpaper until at least two coats of oil or varnish have been applied. Sandpaper should be no coarser than "O" grade.

The wood selected is of absolutely clear and straight grain with

no discoloration. The laminations are piled so as to have the edge of the grain on the face of the blades. The direction of the annular rings are alternated in adjacent boards.

The extreme tips and sometimes the leading edge are capped with thin copper sheathing to protect the blade from injury due to striking insects or rain while revolving at high speed. This sheathing principle is illustrated in Fig. 82.

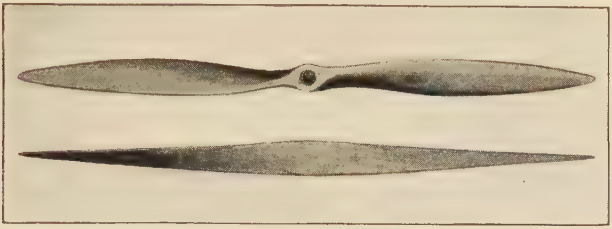


Fig. 83.—Forged metal propeller.

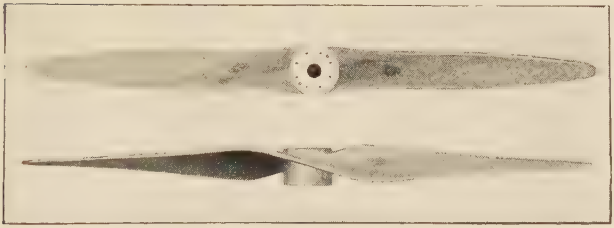


Fig. 84.—Rolled metal propeller.

While the wooden propeller will be found on many planes, those made of metal prove the most popular. The metal propeller does not cause as much trouble due to changing climatic conditions and are much more durable. Aluminum alloys and duralumin are the metals used, each alloy having its own special heat treatment requirements carefully taken care of by the manufacturer. They are either forged or made from rolled plates twisted at the center to provide the proper pitch angle at the hub. Fig. 83 illustrates a forged design and Fig. 84 a rolled plate design. Castings would not

Fig. 85.—Standard steel propeller, variable pitch type.

do because of the danger of flying to pieces at high velocity. Metal blades can be made very thin, with almost knife sharpness. While wooden propellers deliver about seventy-five to eighty per cent efficiency, the metal type has been found to deliver from eighty per cent upward.

In order to make a propeller adaptable to different types of airplanes, methods have been devised and experimented with to vary the pitch of the propeller blades. This, of course, necessitates the adding of the parts needed to supply the varying mechanism. This adds to the weight of the propeller and it is a question whether the added convenience of the varying is overcome by the loss in efficiency of the whole plane due to the added weight. Variable pitch has been practically abandoned with wooden propellers, but has been used considerably in metal construction.

For an occasional and rare necessity, change of pitch is made on the ground while the plane is at rest. Automobile manufacture has taught us that it is a grave mistake to encourage alterations in design, and a propeller is designed to operate on a particular plane with a particular engine. Serious accidents have already occurred, proving the danger of changing propeller pitch with the change of fancy of anyone who happens to own an airplane. Pitch changes should never vary over three degrees from that originally set by the manufacturer under any circumstances.

Fig. 86.—Variable pitch propeller hub.

One type of propeller is built with the blade root, or hub end, tapered which fits into a similar tapered hole in the hub. It is held in place by a ring that clamps around the extreme outer end of the split hub. Tightening the ring wedges the blade root snugly into the hub. There is a "zero" mark on the blade and degrees are marked on the hub. In setting the degree of pitch to that desired, the ring is loosened, the blade tapped loose with either a wooden or rubber mallet and moved so that the desired degree mark lines up with the zero mark. The ring is then again tightened and safety-locked in place. This type requires that the pitch be set while the plane is at rest on the ground and the engine idle.

Care of Metal Propeller Blades.—Whenever there is any sign of pitting or rough spots, caused by striking insects, rain or pebbles, on the leading edge of the blades, it must be attended to immediately. If the pitting is at all bad, the rough edges should be smoothed with a fine file. Care must be taken not to remove any more material than absolutely necessary. After the roughness is removed with a file, the whole leading edge should be smoothed down with emery cloth and finished off with crocus cloth. The filing should be avoided if possible and be used only when the pitting is so extensive as to make its use really necessary. If it is necessary to remove a great deal of material, it may result in throwing the propeller out of balance. This condition must be watched for and corrected.

Ordinarily propellers are sent out from the factory bright, that is, without either paint or protective covering. The best protection for the metal is a thin coat of oil applied by wiping the blades with an oily rag. This should be done after the tips have been touched up with the emery and crocus cloths to remove roughness.

Another form of variable pitch propeller is that operated from the pilot's cockpit. A lever is used to operate a mechanism inside of the propeller hub that changes the degree of pitch while the propeller is revolving. This type is much heavier than the "ground set" type and has more parts, including gears, that are subject to centrifugal force. This type is ideal if perfected because of the ability on the part of the pilot to reduce the pitch and allow the engine to revolve up to high speed, which permits climbing out of a small field quickly, and then after leveling out on an even keel,

the pitch can be increased, thus slowing the engine down but still providing sufficient thrust.

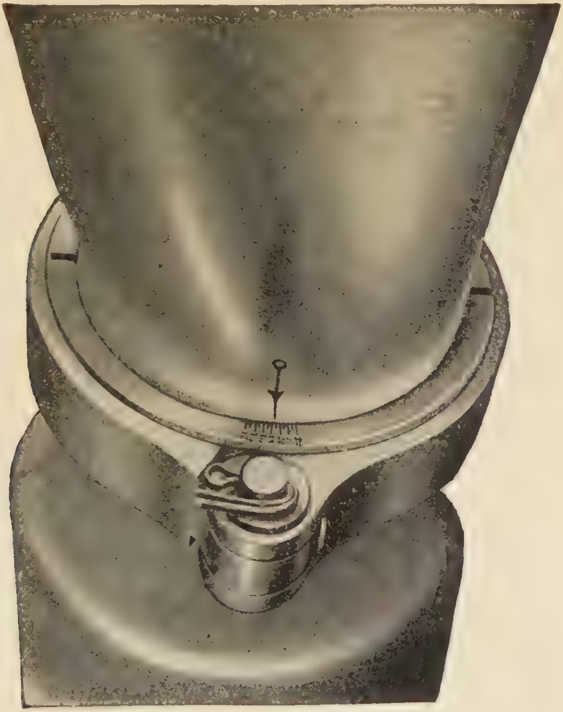


Fig. 87.—Pitch setting scale.

Propellers are usually submitted to a "whirling test" of about 100 hours at perhaps one hundred per cent overload before they are allowed to enter real service. This test is to allow any possible defects to show themselves before the propeller is put into service on a plane. Overload for testing is obtainable only by increasing the number of revolutions, thereby increasing the pull load as well as the centrifugal load. The usual load, for instance, of a ten-foot Liberty propeller is about 500 pounds thrust and a centrifugal load of over ten tons. You can see, therefore, that the blades must withstand tremendous pressure, and when they withstand twice this

amount, one hundred per cent overload in a test, they are all right for use under ordinary conditions.

Some propellers are attached to the engine through the medium of a separate flanged hub splined to the tapered and extended engine crankshaft. Bolts pass through both the flanged hub and propeller hub holding them in a rigid assembly. The whole is then fastened to the driving shaft by a nut and lock nut. In the majority of hubs the end nut not only forces the hub onto the tapered shaft but it is also constructed so that it can be used for pulling the hub off the shaft. The nut is double threaded, inside and out, the inner thread being coarser than the outer. Screwing the nut in forces the propeller hub onto the taper, turning the nut out pulls the hub off the taper as the inner threads gain in travel.

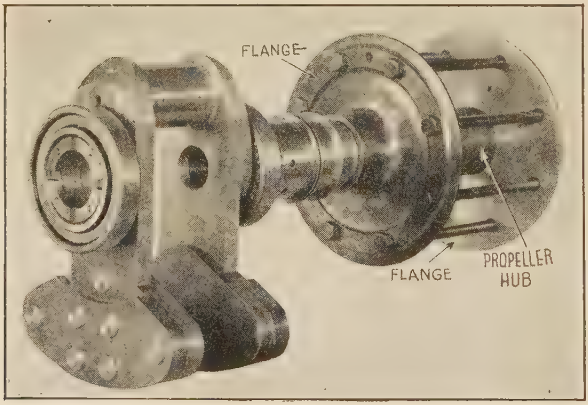


Fig. 88.—Crankshaft and flanged propeller hub.

In fitting a flanged propeller hub the work must be done very accurately so that there is no slack or lost motion present. Great care must be taken to center exactly and fit the hub to the bore of the blades, i.e., the hole provided in the center of the blades for the flanged hub to fit into. The drive is practically wholly through the flange bolts, and for this reason they must be uniformly tight if each is to take its proper share of work and not pound the bolt holes out of shape.

If the hub is off center the least bit, terrific stresses will be

thrown on the shaft and bearings through the unbalanced centrifugal force. This unbalance is a frequent cause of bent or broken shafts and broken propeller blades.

Continued presence and the effect of moisture on wooden propellers will cause the hub bolts to loosen in time. If the bolts are loose to start with, the continual driving impulses will hammer the bolts against the wood and powder it until the propeller has actual play at the hub. If this play develops, trouble follows quickly.

The propeller blades must be lined up so that each tracks directly behind and in the identical path of the other, otherwise flutter and vibration would be produced to a high degree. This is done by turning one blade down, the propeller standing perfectly perpendicular, and measuring from the tip to some point on the landing gear. Then the other blade is turned down and the same measurement taken. If the two differ it is necessary that the blades be shimmed at the hub so as to bring the blades into a position where the two measurements are identical.

CHAPTER XII

RIGGING AND ASSEMBLING

ONE of the most interesting parts of aviation is the assembling and rigging of the airplane. It is much more interesting than assembling and lining up an automobile and it is certainly much more important in the manner in which it is done. An automobile is lined up for roadability by having the wheels "track" so as to require the least amount of effort to keep it traveling straight ahead. This might be called directional stability. The airplane must not only be "tracked" for direction but also for up and down and sideways.

The tracking of an airplane is done by so adjusting the wing surfaces that they present the proper angle of attack to the relative wind. When this is done properly the modern plane will all but fly itself when the pilot's hands are off the controls, one manufacturer going so far as to advertise his product as "the plane that flies itself." The work, or art as it might be called, of so adjusting the various surfaces to their proper angles is called *rigging,* and the person competent to do this work is called a *rigger.*

An airport rigger's work is not ended, however, when he has assembled or rigged a new ship or re-rigged an old ship. He must also see that the airplane is maintained in this condition and check the various dimensions from time to time. The surfaces will get out of line from the excessive strains and stresses thrown on them while flying, from hard landings and from various other causes. The rigger should also watch for signs of parts deteriorating and replace them immediately. This last is very important because if a vital part gives away in the air there is no convenient curb to pull to and repair the damage.

The aviation workman, to be really efficient, must have a genuine and personal interest in the work. He must feel his responsibility

and realize that upon his work and effort depends the uninterrupted and perfect working of the ships under his care.

Another thing you will notice about a real aviation mechanic is that he will use the proper tool for the work he is doing. If a wrench is supposed to be used he will not substitute a pair of pliers just because a wrench is not handy. He won't use a center punch where he should use a drift punch, and when it comes to working with a hammer, he uses the utmost caution. It is very easy to damage certain parts of a plane by using wrong tools, and this is not tolerated around an airport. Neatness and orderliness are two of the first habits formed by the rigger after he has learned to be thorough. He never leaves one job until it is finished. If he did he would soon have several jobs partly finished and probably leave some of them only partly finished when it came time for the airplane to take to the air. Haste is an evil not tolerated by the real mechanic. He never fails to lock every safety device, cotter pin and safety wire all parts before the plane under his care leaves the ground. He won't be hurried under any circumstances. He always remembers that human lives, including perhaps his own, depend upon his work.

Bolts and clevis pins should be inserted properly—never forced where they should fit snugly.

An important rule of rigging is: *Keep the airplane clean!* A coating of dust, grease or oil may hide some careless piece of workmanship or a worn-out part. Fabric and wood are also rotted by grease or oil. A plane should be gone over carefully and cleaned before putting it away after being in the air. A rag run over all of the wires will catch in any frayed or broken strands, telling the rigger of parts in need of replacement. You will notice that pilots and riggers invariably do this before or after taking a ship off the ground.

The "air test" tells the rigger of the success or failure of his job of rigging. Two ships of the same make and design may be rigged exactly alike and as accurately as possible, but when they take the air they will, in all probability, vary greatly in their performance. Unless the rigger is also a pilot he must rely upon the pilot entirely for information, and on this information base his readjustment of the angles.

A pilot who is not also a rigger usually has less time, or else does not take the time, to examine and check his machine while on the ground. This kind of a pilot is less apt to detect possible faults before he takes to the air, and it is usually too late after he does. A pilot will almost always trust his rigger faithfully to have the plane properly rigged before he allows it to be rolled out to the starting line. Full coöperation between the pilot and the rigger is of the greatest importance, but nevertheless a pilot should have a knowledge of how to rig his ship. When he has this knowledge he can oversee and direct a comparatively inferior mechanic, although any mechanic who is not conscientious and thoroughly trustworthy should never be allowed to work around an airplane.

One of the first things to learn about rigging is not to rig too tightly—in other words, do not make the wires and bracing struts too tight. This would only strain the fittings and place loads on the parts far above those originally intended. A ship gives and weaves to a certain extent under the force of sudden wind pressure. If it did not, fittings might pull out and wires snap. Another important thing to understand is the proper way to handle airplane parts. Crates made to fit the particular part should be used when shipping, suspending the part at its strongest points always. Each major part should have a crate by itself, the fuselage, the engine, the wings, the tail surfaces, etc.

When setting a wing surface down anywhere it is best practice to let it stand on its leading edge because this is the stronger of the two. When shipping, the surfaces should be made to rest on their leading edges with pads underneath.

Whenever it is desired to support the fuselage, or a complete airplane, in any other way than on its own landing wheels and tail skid, the supporting structure should be placed at a joint in the framework and never at a point part way along a longeron. Padding of some kind, cloth or cotton waste, should always be used to guard against possible damage to the fabric or wooden parts. The airplane was originally designed to have its weight supported by the landing gear and tail skid. If these parts are removed for repairs or to be replaced, care must be taken in supporting the rest of the ship. It is not good practice to support it at points other than where the landing gear and tail skid are attached, because

any other part is not designed with sufficient strength to support the weight. One good way is to rig a sling of rope, padded, at the point where the landing gear is ordinarily attached and use a block and tackle to hold the ship in the air.

TOOLS

The tools required by the rigger for assembling and adjusting the surface angles are few and simple. A selection of pliers, round-nosed, flat-jawed and wire cutters; several end-wrenches to fit various sizes of S. A. E. bolts and nuts; one or two adjustable end-wrenches; small, medium and large screw drivers; a lead or brass hammer of about three-quarters of a pound weight; a ball pein hammer of the same weight; a drift punch to line up holes through which it is necessary to place bolts or pins, completes the hand tools.

Certain measuring tools or instruments are also needed to measure the angles and test the accuracy of the machine. Some of these instruments can be made by the rigger, others can be purchased from any good aviation supply house. Straight edges of various lengths, trammels, a steel tape, an ordinary spirit level, such as is used by carpenters, a bobbin and line, and a clinometer (incline-meter) are among the instruments needed. If some of these sound complicated don't worry; each one is described, illustrated, and its use explained. Look at the drawings of the various tools and you will better understand how they are used and what they look like.

Straight Edge.—A straight edge, as you know, is simply a perfectly straight strip of wood or steel, preferably the latter. Several straight edges of various lengths should be kept on hand for rigging work. The chief use of straight edges is to check the trueness of parts supposed to be straight and also to check the level of relative parts, as that of the two top longerons.

Plumb Line and Bobbin.—The plumb line consists of a length of stout string and the bobbin is a pointed weight attached to the string's end, the bobbin looking quite similar to a boy's top. The plumb line and bobbin is used to check vertical accuracy. The plumb line is usually of stout fish line and can be used to stretch tightly between two points to designate a straight line between them.

Clinometer.—A clinometer is really a straight edge in a different form and having an adjustable spirit level attached. This instrument, one type of which is illustrated in Fig. 89, is used for checking angles that differ slightly from the true horizontal, such as the angle of incidence.

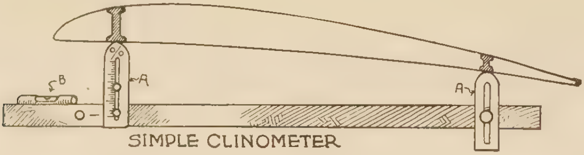


Fig. 89.—Clinometer.

The instrument has two fingers, *A–A*, which are movable and held in place by set screws. The illustration shows the way it can be used to check the angle of incidence of the main wing. The adjustable fingers are set so as to touch the under side of the wing and the straight edge part made level by the spirit level attached to it at *B*. The fingers *A–A* are marked in graduations of degrees and the angle of the surface being checked can be determined by the reading on the graduated scale.

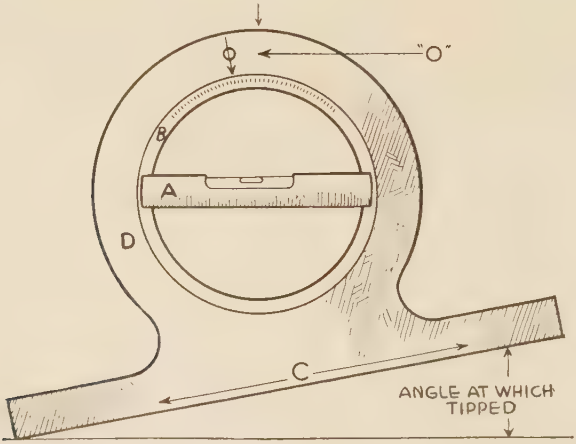


Fig. 90.—Clinometer.

Although the clinometer described can be used, other types more suited to rigging work are shown in Figs. 90 and 91. Fig. 90 illustrates a short straight edge *C* to which is attached a spirit level *A*. The spirit level is mounted in a frame *B* which in turn is free to rotate in its frame *D*. In practice this clinometer is placed on whatever length straight edge you are using at the time and the frame tipped to conform with the angle of the straight edge. The spirit level, in its frame, is then rotated to a point where the bubble is in the exact center. The level frame is graduated in degrees and is read at point *O* on the outer frame

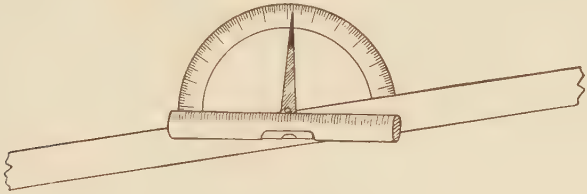
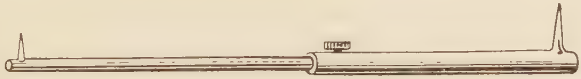


Fig. 91.—Clinometer.

Fig. 91 illustrates another type of clinometer, less expensive and easily made by the rigger. A pointer is attached to the exact center of the spirit level and then pivoted to the straight edge. A scale graduated in degrees is attached to the straight edge, and with the straight edge against the surface to be checked, the level is moved until the bubble is in the center. The pointer will then indicate on the scale at what degree the straight edge is tipped.



TRAMMEL

Fig. 92.—Trammel.

Trammel.—A trammel is simply a light rod that slips inside of a close-fitting tube, thus making it adjustable as to length. On each end of this device is a sharp pointer. The trammel is used for the accurate comparison of lengths.

This completes the list of tools necessary, with the exception of everyday familiar tools such as the steel tape.

Fittings.—A fitting is the connecting link between airplane parts, made of metal and shaped so as to fit both parts to be attached to each other. A wing, for instance, is not fastened directly to the fuselage. A metal fitting accomplishes the purpose. Interplane struts fit into a metal socket fitting which is fastened to the wing.

Turnbuckles.—A turnbuckle, of which many are used in the construction of an airplane, is a device for shortening or lengthening a wire or cable bracing, illustrated in Fig. 93. One end, *A*, is attached to a fitting by either a pin or a bolt. This end may have a right hand thread. The cable or wire is attached to the other end *B* by being run through the "eye" and spliced. If end *A* had a right hand thread, the other end, *B*, would have a left hand thread. The center part *C* is right hand threaded in one end and left hand threaded in the other. Turning the center part *C* in the proper direction while engaged with the threads of both end parts would tend to screw it onto both ends at the same time, drawing them toward each other, resulting in a shortening of the cable or wire. Turning the center part in the opposite direction would, of course, accomplish the opposite result.

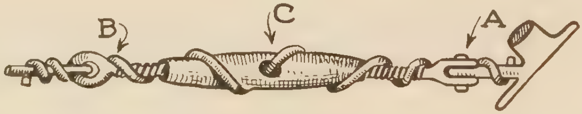


Fig. 93.—Turnbuckle.

Safety Wires.—Unless some method of securing the center section of the turnbuckle were employed the vibration would eventually cause it to unscrew, lengthen the cable and cause a slackness. Therefore a small special alloy copper wire, of about twenty gauge thickness, is used to "safety" it. The wire is anchored by wrapping it through the eye in one end, then it is run through the small hole in the center of the center part *C*, out the other side and again anchored to the opposite end part, as shown. This locks the turnbuckle securely and prevents it from unscrewing.

Streamline Wires.—The turnbuckles are for use with round cables and, as we learned before, round objects present a resistance to air flow. For this reason round cables have been replaced in modern airplanes, where they must be placed outside in the air

stream, with a streamline wire. This type is really a round piece of very high grade steel flattened for its full length except at the extreme ends. The ends are left round and threaded, one end with a left hand thread and the other with a right hand thread. The ends are then screwed into fittings having like threads. Adjustment is accomplished by turning the whole length of the wire and safetied by tightening the lock nuts shown in Fig. 94.

Fig. 94.—Streamlined wire.

Wire Bracing.—The whole airplane structure is held rigid and the parts in proper relation to each other by properly placed and adjusted wire bracing and struts. There are a great number of both wires and struts, each one having a name. Look at Fig. 95 as I describe the wires shown.

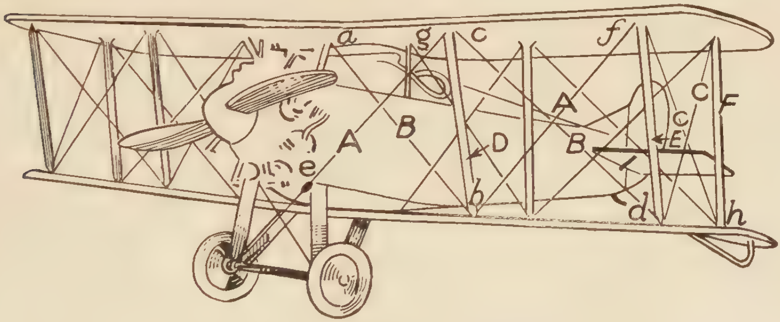


Fig. 95.—Bracing of an airplane.

The wires B running from a to b and c to d are landing wires and take the weight of the main wings while the plane is on the ground. The whole ship is supported by the landing gear, through the fuselage to a where the top wings are attached. By placing a wire from a to b and from c to d the weight of the wing is carried by the cabanne strut placed between the top longeron and the under side of the top wing. These wires and struts are duplicated at the back of the wings and on the wing panels on the opposite side of the ship.

When the plane is on the ground the flying wires *A* should be noticeably slack but not too slack, because if they were, the landing wires would be equally slack when the plane is in the air, causing excessive vibration.

When the plane is in the air the supporting medium is reversed. Instead of the landing gear holding the fuselage and wings up, the wings hold the landing gear and fuselage up. The fuselage and landing gear tend to sag toward the ground and are prevented from doing so by the flying wires *A* running from *g* to *e* and from *f* to *b*.

The wires *C*, crossed in the form of an *X*, running from the outer front strut to the outer rear strut, are called the incidence wires. Struts of hollow steel tubing, streamline shaped, are being used a great deal instead of the incidence wires. In this form of construction the assembly of interplane and incidence struts forms the letter *N*, as illustrated in Fig. 1, and is referred to as the "N-type" construction.

Changing One Adjustment Affects Others.—Changing the adjustment of one wire will invariably affect the adjustment on other wires. For instance, you might increase the dihedral. To accomplish this you shorten the landing wires *B*, increasing the distance from *e* to *g*. Therefore the flying wires *A* must be lengthened to correspond with the increased distance from *g* to *e* and from *f* to *b*.

Rigging Procedure.—Before an accurate check may be taken of any part of an airplane it must be placed in a flying position, the position it would assume in normal flight relative to the horizontal. This can be done by supporting the tail the correct distance off the ground by a trestle, properly padded.

Manufacturers usually place two projections on one side of the fuselage near the cockpit and about two feet apart. The exact position of these pieces is determined at the factory and are placed so that when a spirit level is laid across them and the bubble is in the center of the glass, the ship is in its flying position. Other ships are in a flying position when the engine crankshaft is level fore-and-aft. Which method to use is outlined in the instructions for rigging the particular ship.

The ship is next checked for lateral level by placing a spirit level across the two top longerons, tipping the fuselage until the bubble registers level. This flying position must not be disturbed while

assembling and rigging the rest of the ship, and should be checked for accuracy after attaching each unit and rectified before lining up. If this is not done it may be found that, after carefully lining up and leveling the added unit, the fuselage has been out of level during the whole operation, making the whole thing a wasted effort. As the assembling of the ship progresses, each part should be trued up before attaching. Each type of airplane is rigged differently with different angles, etc., and the truing up will conform to the maker's instructions.

In the later type modern airplane the fuselage frame is made of steel tubing welded at the joints. In this construction very little rigging or truing up of the fuselage will be necessary except in case of accident. Badly bent sections should be replaced—it being unsafe and bad practice to straighten steel tubing with more than a ten degree bend. In some cases the steel tubing will be braced with cable, adjustable by turnbuckles. Inasmuch as all other parts of the airplane are attached to the fuselage, it is the first part that should be checked for accuracy. If found out of line, the longerons and struts may be drawn back into line by tightening some cables and slacking off on others.

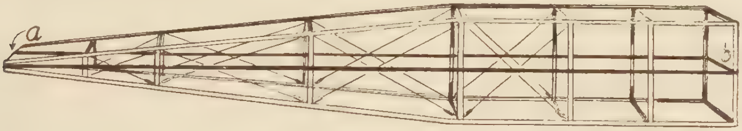


Fig. 96.—Datum line.

The manufacturer will mark a point in the exact center of the extreme front cross strut and another on the rudder post, corresponding to the points marked *a* and *b* in Fig. 96. These points are called "datum points," or starting points. Both longerons should be an equal distance from a plumb line stretched tightly between the datum points when the fuselage is true directionally. Datum points are also marked on each cross strut from nose to tail and the plumb line should line up with these.

Datum points are also marked on the upright struts on each side of the fuselage that reach from lower to upper longeron. The datum points should be made to line up with a plumb line stretched

from the extreme forward strut to the rudder post in order that the fuselage may be true up and down.

If necessary to tighten one brace cable the opposing cable should be first slackened. If this procedure has been necessary to line up the fuselage, the level of the whole assembly has undoubtedly been disturbed so it should again be checked with a spirit level.

The welded steel tube framework does not lend itself to easy adjustment. Naturally this type of framework is not going to get out of line easily. This eliminates the necessity of frequent truing up, as is necessary with wooden-frame construction. Except in the case of accident the steel tube frame will need very little attention. If it is necessary to replace a damaged section it means a welding job, and the rest of the framework is held in accurate line-up by cable braces while welding.

After the fuselage is trued up the landing gear is usually attached. This is a comparatively simple operation of placing the wheels on the axles and slipping the struts into their proper sockets and bolting them there. With the ordinary type of landing gear the only dimension that does not automatically align itself is the crosswise, or diagonal. This dimension can be brought into line by trammeling the brace struts or the cross brace wires, as the case may be.

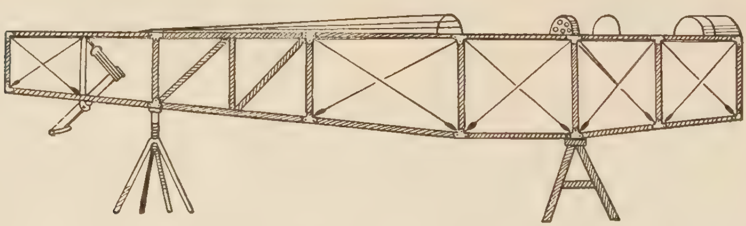


Fig. 97.—One method of tail skid anchoring.

The tail skid is the next part assembled, being attached by the hinged fitting to an internal strut near the rudder post. The upper end of the tail skid is anchored either by rubber rope, heavy spring or a hydraulic shock absorber, to the skid strut.

Center Section.—A separate section of wing surface, made independent of the main wings, is placed between the upper main

wings and braced rigidly to the fuselage. This smaller section acts as an anchor for the main wings of a biplane, and is called the center section. It is attached to the top longerons by struts, adjustable as to length, so that the section may be trued up with the use of the clinometer or straight edge and level.

It is most important that the center section be rigged and trued up accurately because the accuracy of the main wings, which attach directly to it, depends entirely upon this fact. The section may be assembled loosely and then trued up.

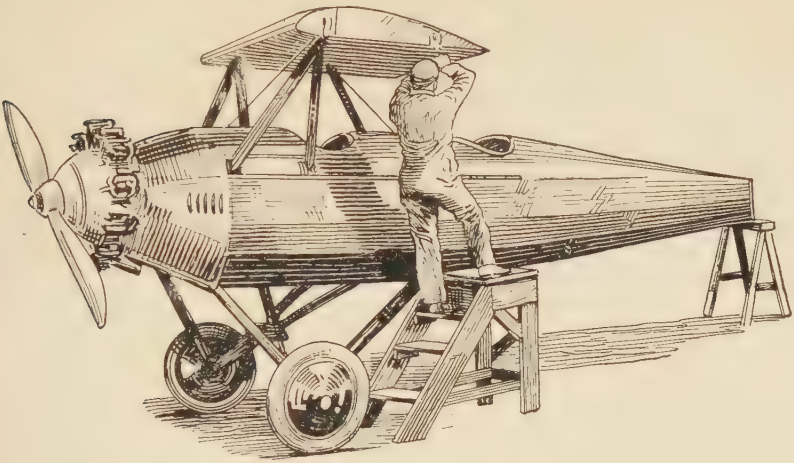


Fig. 98.—Rigging the center section.

First a center point is marked on the leading edge of the center section, an equal distance in from each side. A plumb line and bobbin is then hung from this center point. By adjustment of either the diagonal brace wires or the struts, as the case may be, the bobbin is brought directly over the plumb line already stretched between the front and rear datum points. The rear bay of the center section is centered in the same manner by hanging the plumb line and bobbin from the center of the trailing edge. The proper angle of incidence can be obtained by adjustment of the front center section struts using the clinometer to check the accuracy.

After the section is centered, adjustment of the angle of inci-

dence may alter the first adjustment so each preceding adjustment must be checked over again.

After the center section is in place and trued up, the main wings are attached. The exact manner of doing this will vary with the different makes and forms of interplane bracing. If only one set of struts are used the wings must be attached as separate units, one at a time. The top wings are attached first, supporting the tips to the center section temporarily by propping. The lower wings are attached to the fuselage through the fittings and their weight can be supported by the upper wings by attaching the landing wires. The interplane struts are next placed and the lower wing will then support the weight of the upper wing.

On airplanes using more than one pair of interplane struts it has been found easier to assemble a complete wing section, an upper and a lower, before attaching to the fuselage. This is done by standing the two wings on their leading edges in their relative positions and then placing the interplane struts and bracing cables fairly tight. The assembly of upper and lower wing is then raised as a unit and attached to the center section and the lower fuselage longeron.

After the wings are attached the first angle to check up and adjust is the dihedral. The front spar of the upper wing is used as a base from which to measure. A plumb line may be stretched from wing tip to wing tip and the distance of this line above the center section spar will be the base of the dihedral angle. A better method of checking the dihedral is to place a long straight edge along the front spar and then use a clinometer to measure the angle. The usual dihedral angle is about three degrees and is obtained by adjustment of the landing wires, although allowance must be made for the slackness of the flying wires which will increase the angle slightly when the ship is in the air. Tightening the landing wires will increase the angle and loosening them will decrease the angle. Once the angle is set the landing wires should not be altered.

Stagger.—Stagger is the distance the leading edge of the upper wing is ahead of or behind the leading edge of the lower wing. The stagger can be measured by hanging plumb lines and bobbins from the leading edge of the top wing and measuring the distance to the leading edge of the lower wing with a steel scale. The

stagger is governed almost accurately by the position of the wing attachment fittings, but can be trued up exactly by adjustment of the incidence wires, or stagger wires as they are sometimes called. When incidence struts are used, the adjustment is, of course, made by them.

Angle of Incidence.—The angle of incidence is that angle which the chord of the wing makes with the true line of level flight. This means the angle of the chord with a plumb line drawn tightly between the front and rear datum points of the upright fuselage struts.

As with the stagger, the angle of incidence is approximated by the position of the wing attachment fittings. Further adjustment may be made on the center section bracing.

The proper angle of incidence, in relation to the fuselage datum line, is obtained by placing the clinometer on the under side of the wing touching both leading and trailing edge. The proper angle of incidence for the particular plane will be designated in the book of instructions, being usually about three degrees.

The incidence near the fuselage is governed by the position of the attachment fittings, farther out the angle may be altered slightly by adjustment of the incidence wires or struts and the landing wires. Altering of the latter bracing should not be extensive because other angles will be altered in consequence, and if any great alteration is found necessary, the center section should be again checked for accuracy because the fault will usually be found there.

Wash-In, Wash-Out.—It is very seldom that the incidence at the tips of both right and left wings is the same, a difference being made to present different angles of attack to compensate for the torque of the engine. On the side tending to be forced down the angle is increased to provide additional lift here, and on the side tending to be forced up the incidence is decreased, reducing the lift exerted there. The wing tip having increased angle of incidence is said to have *wash-in,* and that having reduced incidence is said to have *wash-out.*

The angle of incidence, as well as other angles, may require slight readjustment after the airplane has undergone an air test, because, as said before, practice is better than theory, and a "book-rigged" ship will very seldom fly in perfect balance.

Sweepback.—When the wing leading edges are not exactly at right angles to the fore-and-aft datum line, it is called *sweepback.* This angle is sometimes adjustable by drift wires running from a rigid anchor on the fuselage to well out on the wing, tending to overcome the tendency of the wings to fold back against the fuselage through the force exerted by the wind. The drift wires should not be too tight and should take no strain except when the ship is in flight. The steel tape is used in checking the accuracy of both sides of the wings as to sweepback by seeing that the drift wires are both of the same length.

Attachment of Tail Surfaces.—The tail surface group, consisting of the horizontal stabilizer, vertical stabilizer, elevators and rudder, is attached next. The proper angle of incidence and other angles for these surfaces will be noted in the instruction book for the plane.

The horizontal stabilizer is attached first, as a rule. A variable adjustment is provided for this surface so that its angle of incidence may be altered to provide more or less lift as desired for varying loads the plane might be called upon to carry. This adjustment is accomplished through an attachment on the stabilizer leading edge and fuselage and operated by the pilot in the cockpit. If a variable adjustment is used it should be set midway between its two limits of travel and the stabilizer normal angle of incidence set at this point.

The vertical stabilizer is next attached, its angle in relation to the true fore-and-aft datum line being determined by the amount of torque exerted by the engine in attempting to veer the ship off from a straight-ahead line of flight.

The lateral level of the horizontal stabilizer and the vertical truth of the vertical stabilizer are checked with the spirit level and the brace wires tightened when both are accurate. The incidence of the horizontal stabilizer is checked with the clinometer in the same manner as were the main wings.

The brace wires for these surfaces should be adjusted a little at a time and no one of them tightened completely before the others are of equal tension. The length of opposing relative wires should be made equal and measured with the trammel.

The trailing edge of the horizontal stabilizer should be exactly

square with the fuselage. It is checked by measuring with the steel tape from the outer interplane strut lower socket to the outer tip of the stabilizer trailing edge on the same side of the ship. This measurement should not be taken until the whole ship is again checked for accuracy as to flying position, main wing level, sweep-back and stagger.

After this has been done and the stabilizer lined up, the elevators and rudder are attached, having first been trued up by adjustment of their internal bracing. The control cables or rods are attached, and at this stage of the assembly, it is best to go over all work done so far and cotter pin or safety wire all places requiring it. It is too easy to overlook the many small lock nuts, hinge pins, cotter pins and turnbuckles to get too far ahead with the work without finishing this highly important detail. Each very small item is important to the safety of the plane, and unless one section of work is finished completely before another is commenced, costly oversights are apt to occur.

The ordinary assembling and rigging of an airplane means simply the putting together and adjustment of the various parts in relation to each other. The actual construction of these parts concerns only the manufacturer. The work necessary to rebuild a ship that has been crashed seriously is therefore similar to that of a manufacturer, because all damaged parts that are not perfectly sound must be rebuilt unless it is possible to purchase the part new.

When using any part of a damaged ship for rebuilding, a careful inspection should be made to see that there is no possibility of a flaw in it. When repairing damaged wooden framework, some knowledge of the cabinet maker's art is almost essential. When working on metal construction a knowledge of steel, duralumin and welding is necessary.

Air Test.—After the ship is completely assembled and rigged according to specifications, it is ready for an air test. All dimensions should be given a final check before the actual air test to make sure that they are correct.

Even so, when the ship is flown on its maiden trip, it may be found that it does not fly exactly level—it may be tail heavy, for instance. This means that the tail seems to be extra heavy, causing the nose to want to point up with the control stick in neutral and

requiring extra exertion on the pilot's part to keep the nose down to level flight. This shows that the horizontal stabilizer requires an increase in its angle of incidence, producing more lift at this point.

The ship may be found to be nose heavy, meaning that it tends to nose down when the stick is held in neutral, and that the angle of incidence of the horizontal stabilizer is too great.

If the ship tends to veer off in one direction or the other, called *yawing*, with the rudder bar in its neutral position, it means that the vertical stabilizer is not accurately lined up. Yawing to the left requires that the vertical stabilizer leading edge must be set farther to the left of the true longitudinal center of the ship. If yawing right, the stabilizer leading edge must be set farther to the right of the true longitudinal center of the ship.

It may be found that with the control stick in neutral one wing tends to droop, or is wing heavy. This can be overcome either by giving the wing tending to droop wash-in or the wing flying high wash-out, depending upon the amount of original angle of the particular wing.

CHAPTER XIII

AIRCRAFT INSTRUMENTS

A DESIRE and the necessity of knowing accurately the performance of an airplane have resulted in the invention of many and varied instruments which have all but eliminated the old careless haphazard method of flying blind. The instruments have been so highly perfected that it is possible for the pilot to be entirely enclosed but still guide the ship through the air on an even keel.

Instruments that might ordinarily be used on automobiles or boats are not suited to airplane work because of the added strains placed upon them by the vibration of the engine running at high speed, the air pressure and temperature varying with altitude, the shocks experienced when landing or taking off and throwing them off an even keel while climbing, banking or gliding. Any one of these adversities might cause an ordinary instrument to function improperly or not at all. The size and weight of the instrument are very important also—space is usually at a premium and every ounce of added weight reduces the efficiency of the plane.

Instruments used on airplanes may be divided into three groups:

1. Power plant instruments.
2. Airplane performance instruments.
3. Navigation instruments.

The following are included in the first group:

a. Tachometer.
b. Gasoline pressure gauge.
c. Gasoline quantity gauge.
d. Gasoline rate-of-flow gauge.
e. Oil pressure gauge.
f. Oil quantity gauge.
g. Oil "in" temperature and oil "out" temperature gauge.
h. Water temperature gauge.
i. Ammeter (when electric starting and lighting are used).

These are some included in the second group:

a. Altimeter—shows altitude.
b. Air speed indicator.
c. Turn-and-bank indicator.
d. Rate-of-climb indicator.

The third group includes the following:

a. Compass—either magnetic or earth inductor type.
b. Drift indicator.
c. Sextant (used only on very long trips).
d. Radio beacon receiver.

The above list may seem like a lot of instruments, but for ordinary everyday joy-ride flying they are not all necessary. You will hear all of them mentioned, however, when talking "shop" with an airman, so it is necessary to explain their use and operation.

While reading this chapter remember what was said in Chapter III about air having density and exerting a pressure on objects, the pressure decreasing with height above sea level. Also remember that air creates a suction, commonly called vacuum, and also exerts a pressure on objects that obstruct its flow. All these properties have an effect on, and provide the operating medium of, many aircraft instruments. Several of them use these facts in measuring altitude, miles per hour, amount of turning, etc.

Tachometer.—This instrument indicates the number of revolutions per minutes of the crankshaft, the pulse of the engine, and is one of the most handy instruments about the engine. It is of the distant indicating type because the operating part, attached to a revolving part of the engine, is some distance from the indicating dial which is usually mounted on the instrument board.

The two parts are sometimes connected with a flexible chain similar to that used in automobile speedometer operation. It might be connected to the engine camshaft, in which case it is geared to indicate the revolutions per minute of the crankshaft just the same, the dial being calibrated to the correct ratio.

An engine is supposed to be able to turn over a certain number of revolutions per minute when in proper running order. If for any reason, with open throttle, the greatest possible number of revolutions are below normal, the tachometer immediately indicates the fact and the pilot is notified that something is wrong.

A gradual decline in the number of revolutions obtainable from day to day may indicate a loss of compression and power due to valves in need of grinding, piston rings worn or oil becoming thinned out from continued use. A gradual decline in the number of revolutions over a short period of time while flying, for instance, may indicate that the throttle has closed from vibration. If the gradual decline takes place with the motor laboring harder and harder, it may indicate the oil supply getting low, or the oil system gone wrong and the increased friction pulling the motor down. Too steep a climbing angle will cause the motor to labor also. A decline in revolutions accompanied by undue vibration may indicate that one or more cylinders are missing fire due to a valve sticking, faulty spark plug, or possibly a broken valve spring. A damaged propeller will also cause excessive vibration.

The adjustment of both spark and mixture can be made for the highest efficiency while on the ground by watching the revolutions indicated on the tachometer.

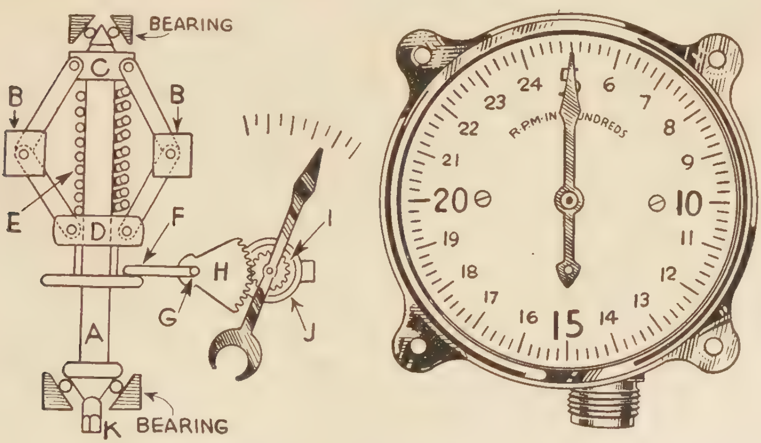


Fig. 99.—Mechanism of the centrifugal flyweight tachometer.

There are several types of tachometers, the exact type used depending upon the distance away the indicating dial is from the operating part. Those operated within twenty-five feet of each other are usually connected by the flexible chain or flexible shaft.

At a distance greater than twenty-five feet the flexible shaft becomes less efficient and other types are used.

The type of head, or indicating part, used on the majority of common tachometers operates on a principle very similar to that of a throttle governor using flyweights. The dial and typical inside mechanism of this type are illustrated in Fig. 99. The center shaft *A* is caused to rotate rapidly by the flexible shaft from the engine which is attached at *K*. The shaft *A* is carried on ball bearings and is in one piece through to *C*. *C* is an upper collar attached solidly to the shaft, and flyweights *B* are attached to the collar through the connecting links shown. These links are hinged to *C*, to the weights *B* and again to the lower collar *D*. The lower collar is loose on the shaft *A* and free to slide up and down.

When the shaft *A* is revolved rapidly, centrifugal force tends to throw the weights *B* outward and through the connecting links lift the lower collar *D* against the pressure of the spring *E*. The collar *D* tends to lift the small lever at *F* which is hinged at *G*. As the lever *F* is raised, the toothed quadrant *H* is lowered and, being in mesh with corresponding teeth on the indicator hand *I*, moves the hand over the dial face of the instrument. The small hairspring *J* is to keep the lever *F* on its seat on the lower collar *D*.

The faster the shaft *A* revolves the farther out the flyweights are thrown, the distance being governed by the tension of the spring *E* which tends to keep the two collars, *C* and *D*, apart. The spring tension is adjustable by lowering or raising the collar *C* on the shaft.

There are several variations in the exact mechanism of the centrifugal tachometer, but the foregoing explains the general principle of them all.

Electric Tachometer.—When the two parts of the tachometer are of necessity farther apart than twenty-five feet, electricity is very often used as an actuating medium. The parts then are a small generator and a voltmeter. The faster the generator is caused to revolve the more volts it generates and the farther the indicating hand is moved across the dial, which is calibrated in revolutions per minute instead of volts. The electric current is handled through wires and the distance between the operating and indicating part is of no consequence.

A tachometer should receive all the care of a high-grade watch or clock. When attaching or detaching the flexible operating shaft, great care should be taken not to jam or injure the tachometer bearings. The instrument should be lubricated only with high-grade clock oil and grease that is free from alkali or acid.

Gauges.—The oil, gasoline and temperature gauges are more or less familiar to everyone who knows anything about an automobile. Such gauges used on an airplane operate on the same principle as those on automobiles but are of better material and finer construction. A pilot or ordinary mechanic very seldom attempts to repair these instruments, as it is better to let an experienced instrument repairman fix them or replace defective instruments with new ones. A knowledge of the principle on which they operate, however, may be of interest and temper your treatment of them.

What is known as a "bourbon tube" is the actuating medium of

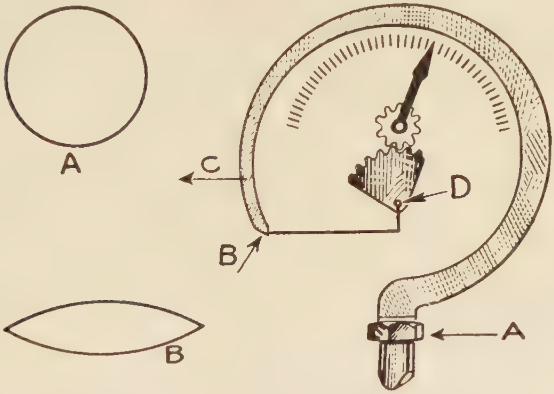


Fig. 100.—Principle of the bourbon tube.

most pressure gauges, such as oil and gasoline pressure indicators. The bourbon tube is made by flattening a circular drawn brass tube, *A,* Fig. 100, so that it assumes an elliptical cross section *B.* At the same time it is bent lengthwise into the arc of a circle as illustrated. One end, *A,* is soldered into a connecting nipple and the other end, *B,* is hermetically sealed. Attached to the *B* end of the tube is the pointer operating mechanism.

If a pressure is exerted through the nipple at *A* the bourbon tube tends to straighten out. This exerts a pull in the direction of *C* on the toothed quadrant *D* which in turn moves the indicating hand over the face of the instrument dial. This type of gauge is very sensitive and comparatively delicate but still must function properly under adverse conditions of vibration and temperature changes. Excessive pressure, greater than that at which they will read, may result in injury to the bourbon tube and render its operation inaccurate and useless.

Fuel Quantity Gauge.—The Pioneer Instrument Company have been the leaders in providing modern aviation instruments of every description and the following are descriptions of their product which will be found as standard equipment on the majority of American-built airplanes.

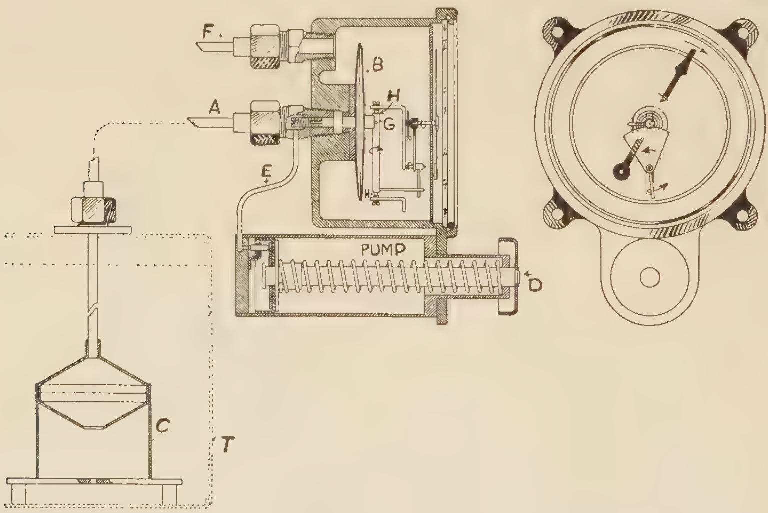


Fig. 101.—Cross section of the Pioneer hydrostatic fuel level gauge.

The operation of the hydrostatic fuel level gauge depends upon the fact that the pressure at the bottom of a tank containing liquid is in proportion to the height of the liquid. "Hydro" means liquid, and "static" means "acting as weight, but not moving." So hydro-

static means liquid acting as weight and in this case pressing against air, tending to force the air out of the tank.

A cross section of the Pioneer hydrostatic fuel level gauge is illustrated in Fig. 101. At the bottom of the gasoline tank T is a cell C which serves as a measuring point for the liquid pressure. The bottom of the cell C is connected by small holes to the interior of the main tank, thereby allowing the liquid to enter the cell. The top of the cell is connected by a tube A to the inside of the diaphragm B. The diaphragm is made by placing two discs of very thin and flexible metal close together with a very small space separating them. As even a slight pressure is exerted on the space between the discs they tend to separate farther; if pressure is exerted on the outside of the discs, they tend to move closer together. A very small and delicate mechanism is attached to the diaphragm in such a way that the indicating hand is moved as the diaphragm expands or contracts.

A small pump D, which is built as part of the gauge, is connected into the tube line A between the diaphragm and cell by a small pipe E. The other connection F, at the top of the gauge, is carried to a point where the main tank is vented so that the pressure within the gauge case, on the outside of the diaphragm, may be the same as the pressure in the top of the main tank above the gasoline. If these pressures were different the diaphragm would not operate properly and would not give an accurate reading.

When the gauge is first installed the tube A will, of course, fill with gasoline up to the level of the gasoline in the tank. The pump D is therefore operated and as air is forced into the tube A, the gasoline is forced out until the cell C is full of air. The pressure which it is necessary to maintain on this air is just enough to keep the gasoline from entering the cell C and in proportion to the depth of the liquid. As this pressure is transmitted directly to the inside of the diaphragm through the tube A the diaphragm will expand a corresponding amount. The diaphragm pushes against a small pin G on a shaft that is mounted in very fine jewel bearings H–H and operating through the links and levers in the direction of the arrows illustrated, causing the indicating hand to assume a position which shows the amount of fuel in the main tank.

Changes in air pressure, due to changes in elevation or altitude,

and changes in temperature cause the loss of more or less air from the cell *C*. This loss may be replaced at any time by operating the pump. The gauge always shows the amount of fuel, subject to the errors caused by the slight loss of air. The exact correct reading may be obtained at any time by operation of the pump, which is only necessary at infrequent intervals.

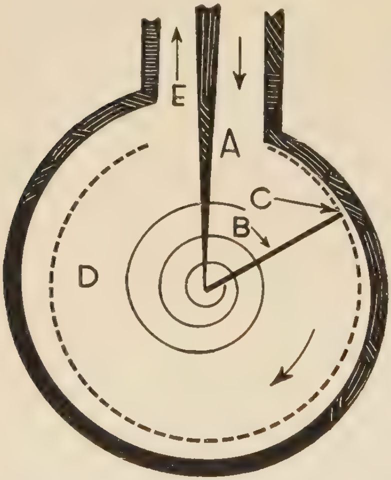


Fig. 102.—Principle of the flowmeter.

Fuel Flowmeter.—A gasoline flowmeter shows the number of gallons of fuel being consumed by the engine per hour. The flowmeter illustrated in Fig. 102 is the R. A. E. (English) and is very steady in its readings. It operates by the gasoline flow pressing on a vane against the resistance of a sensitive spiral spring.

The liquid entering the chamber *A* in the direction of the arrow exerts a pressure on the vane *B*. The only escape for the liquid is through the space *C*, the dotted line indicating the path of the vane tip as it is forced farther and farther around. The space between the vane tip and the instrument case increases as it moves in the direction of the arrow. This is to allow more liquid to escape as the pressure and volume increase. Otherwise a comparatively slight pressure would force the vane all the way around the dial immediately. This space is so adjusted that the readings are evenly spaced to show from five to thirty gallons flow an hour. As the liquid escapes through the space *C* it enters the chamber *D* and is free to flow from there to the carburetor through space *E*.

Temperature Gauges.—The temperature gauges for water and oil are of the conventional type used on automobiles for the same purpose. They are of the distance-registering type, having the indicating dial on the instrument board and the operating part in contact with the liquid.

Altimeter.—Leaving the engine instruments, let us look into those that indicate the airplane's performance. The most common and standard instrument in this class is the altimeter which indicates the height of the plane above the ground. It operates on the principle of the barometer, an instrument used by weather forecasters. The barometer measures the pressure of the air which varies with changes in weather. Air pressure also varies with height above sea level. This fact is used in the operation of an altimeter. There are two kinds of barometers, one using a mercury fluid in a tube and the other using a diaphragm. The former are called mercurial barometers and the latter aneroid barometers.

There are many devices being experimented with to indicate altitude, but those operating on the barometric pressure system are the only ones so far found at all practical. The altimeters in general use today work on the aneroid barometer principle.

The variance in air pressure is measured by the altimeter on a diaphragm, similar to that used in the fuel level guage. The altimeter dial is marked in graduations of hundred-foot units.

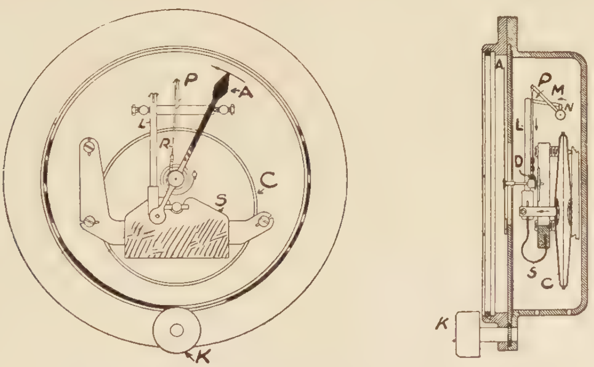


Fig. 103.—Operation of the aneroid barometer altimeter.

Fig. 103 is a cross section of the Pioneer Instrument Company's altimeter. The heart of the instrument is the diaphragm *C* which is evacuated of all air, thus creating a vacuum, and sealed tightly. The normal pressure of the air acting on the diaphragm tends to press the two discs together. This is resisted by the spring *S* which

tends to pull them apart. To this spring is attached the lever *L*, which is connected by the link *M* to the lever *N*. This linkage moves the lever *P* which is linked to the chain *R*. This small chain is wrapped around a drum *D* which carries the indicating hand *A*.

As the plane climbs to higher altitude the atmospheric pressure decreases and the diaphragm expands in the direction of the arrow (in the right hand part of Fig. 103) forcing the lever *L* away from it, which in turn operates the rest of the mechanism in the directions indicated by the arrows.

Inasmuch as this instrument is actuated by atmospheric pressure it is not absolutely accurate at all times, the pressure at the same spot may vary as the weather conditions change. For the purpose of setting the instrument to read zero when desired there is an adjustment provided, shown at *K*. This adjustment rotates the dial face, bringing the zero mark under the indicating hand when desired. The indicating hand, being part of the mechanism, remains in its proper position relative to the atmospheric pressure acting on the diaphram.

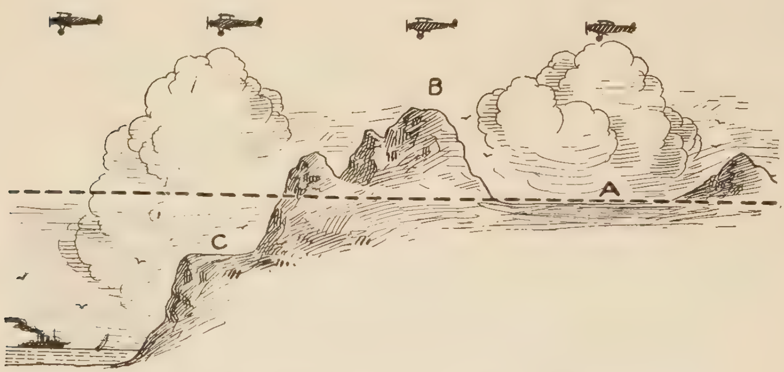


Fig. 104.—Difference in ground elevation does not affect the altimeter.

But even though it is possible to set the instrument to give a zero reading when leaving the ground, the aneroid type of altimeter still has errors because of the fact that it is essentially a pressure-measuring instrument and atmospheric pressure varies with the lo-

cality and weather conditions prevailing even at equal heights above sea level. This fact is illustrated in Fig. 104. Suppose you set the altimeter at zero before you took off from the plateau *A*. You circle until you have one thousand feet altitude directly over this plateau, as shown by the position of the airplane figure. You intend flying toward the ocean and must pass over a mountain peak at *B*. The altimeter still shows one thousand feet altitude, but in reality you may be only five hundred feet above the peak, this is because the atmospheric pressure surrounding the plane over *B* is just the same as it was surrounding the plane when it was over *A*, the plane's height above sea level being the same at both points.

Farther on the plane reaches a point over another plateau *C*, lower than the one *A*. The altimeter still indicates one thousand feet above the take-off point, *A*, while it may be fifteen hundred feet to the ground at C. As you pass out over the ocean it may be twenty-five hundred feet below you, but the altimeter still indicates one thousand feet. This is because the atmospheric pressure at a given height above sea level remains about the same regardless of the earth. How to compensate for this error will be explained in the chapter on navigation.

Air-speed Indicator.—The air-speed indicator is to the airplane what a speedometer is to an automobile, except that the air-speed indicator shows air speed and not ground speed. These instruments are made in three different types; air pressure on a diaphragm, air impact pressure on a flat surface, and rotating propeller type. The most common type in use today is the air pressure on a diaphragm. This type is again divided into two kinds, one using a Pitot tube and the other a venturi tube. The Pitot-tube type measures the pressure of the air entering it, and the venturi type measures the suction of the air passing through it. Most airplane instruments operate by measuring air pressure in some manner using a diaphragm for the purpose.

Pitot Tube.—The Pitot tube, as illustrated in Fig. 105, consists of two tubes. The upper one *S* is called the static tube and the lower one *P* the pressure tube. The static tube is streamlined into the air and its entering end is closed. It has several rows of small static holes about .03 inch in diameter arranged around the tube. These holes are placed about four times the diameter of the tube

back from the entering end in order that the air rushing past may have time to become parallel to the surface of the tube and so produce no suction at the static holes. The static pressure of the air is normal pressure where the air is still and this is what is wanted inside the instrument, as explained later.

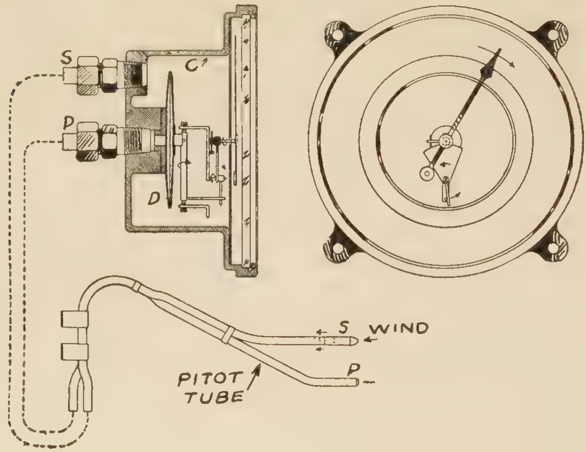


Fig. 105.—Air speed indicator using pitot tube.

The pressure tube as well as the static tube is made of metal tubing, the pressure tube being cut off square and left open to the air.

The tube end of the air-speed indicator is attached to a strut well out of disturbed air other than that passing the ship smoothly, not in the propeller wash. The wind pressure enters the open end of the tube *P* and is transmitted through a connecting tube to the inside of the diaphragm *D* in the instrument head. The total pressure on the inside of the diaphragm is the sum of the velocity pressure plus the static pressure of the free air already in the apparatus. The static pressure in the cockpit fluctuates owing to the flow of air past the ship. These fluctuations would cause incorrect readings on the instruments if not compensated for. It is for such compensation that the static tube is placed near the pressure tube. The static tube is connected to the side of the diaphragm opposite that to which the pressure tube is connected. In this way the static pressures on

both sides of the diaphragm are equal and only the velocity pressure is effective in moving the diaphragm.

The movement of the diaphragm actuates an indicating hand over a dial which is calibrated to show the miles per hour according to the pressure exerted on the diaphragm.

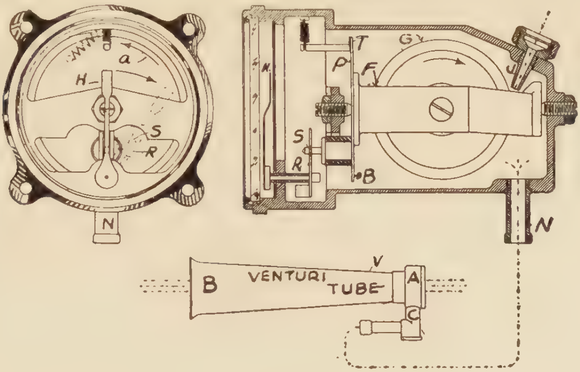


Fig. 106.—Turn indicator using venturi tube and gyroscope.

Venturi Tube.—The tube part of Fig. 106 illustrates a venturi tube. When the venturi tube is used to actuate the air-speed indicator, suction, instead of pressure, is used. The air rushing into the tube at *A* and discharging at *B* produces a suction in the smaller tube *C* which is connected to the diaphragm and indicating apparatus of the air-speed indicator.

Rotating Indicator.—The rotating speed indicator employs a small propeller placed in the free air, undeflected by wing surface or propeller blast causing it to rotate at varying speeds depending upon the speed with which it is moved through the air. These revolutions are then counted in a manner similar to the tachometer. Another type uses a generator attached to the small propeller, the faster the generator revolves the more current generated and indicated on a voltmeter calibrated in miles per hour.

Direct Impact Air-Speed Indicator.—The operating part of the direct impact instrument is a flat surface mounted at right angles to the wind direction. The surface is sometimes mounted on an arm,

hinged or pivoted to the frame of the instrument so that the surface does not remain exactly perpendicular to the wind direction at different air speeds. A light spring is used to resist the force of the wind on the surface. One of the disadvantages of this type of indicator is that it must be mounted in an undisturbed air stream and therefore read from a distance.

Bank and Turn Indicator.—Two instruments are really combined in one in the bank and turn indicator. Referring to that part of the instrument that indicates the turning of the ship, a very common type consists of a combination of two air-speed indicator Pitot tubes, one attached to either wing tip. The dial reading is thereby influenced by the difference in speed of the two wing tips, the wing on the outside of the turn moving through the air faster than the one on the inside of the turn. The pressure pipes lead one to each side of the diaphragm that operates the indicating hand, the one having the greater pressure overcoming the pressure of the other, thereby moving the hand to one side or the other.

The Pioneer turn indicator uses the gyroscope principle and is illustrated in Fig. 106. A gyroscope is a rapidly revolving wheel that tends to continue revolving in the same plane of rotation against the action of forces attempting to change its plane. A boy's top is somewhat of a gyroscope while it is revolving at high speed. The top tends to remain upright and will resist any attempt to change its position while it has sufficient speed. A gyroscope works on the same principle except that it may be rotated at right angles to the ground or in any other angle in relation to the ground and will resist any attempt to change its angle of relationship with the ground from that in which it is rotating.

The heart of the instrument illustrated in Fig. 106 is the gyroscope *G*, which rotates in the direction of the arrow due to the impact of a stream of air from the jet *J*. Air is caused to rush through this jet by sucking the air out of the instrument head case through a venturi tube attached to the case by a length of tubing connected at *N*. The venturi tube is so located that air flows through it, creating a suction.

The gyroscope wheel rotates rapidly on its bearing in the frame *F*. Its axis of rotation corresponds with the lateral axis of the plane. The frame *F* is supported so that it may turn about a fore-and-aft

axis. You can see, therefore, that the gyroscope is free to turn about two axes; one its rotating axis (lateral) and the other the frame axis (longitudinal). The only axis about which it cannot turn is the vertical or turning axis of the airplane. It is a characteristic of a gyroscope that it attempts to rotate about whatever axis it is turned. If the whole instrument is turned, as it is when mounted upon an airplane, the gyroscope attempts to move its axis into the axis about which it is being turned and it does this in such a direction that it would rotate in the same direction as the direction of turn.

Suppose the airplane turns to the right, the gyroscope attempts to move its axis into the vertical so that it, too, may rotate about a vertical axis to the right. Looking at the plate *P*, which is attached to the frame, the top of it, *T*, moves away from you and the bottom of it, *B*, moves toward you. This movement is shown in the front view by the arrow *Q*.

Attached to the plate is a pin, *S*, which engages a fork, *R*, and this fork is attached to the indicating hand *H*. As the gyro unit moves in the direction of the arrow *Q*, the pin *S* moves to the right, as shown by the dotted line in the front view, the fork *R* and the hand *H* are carried to the right, indicating a right hand turn.

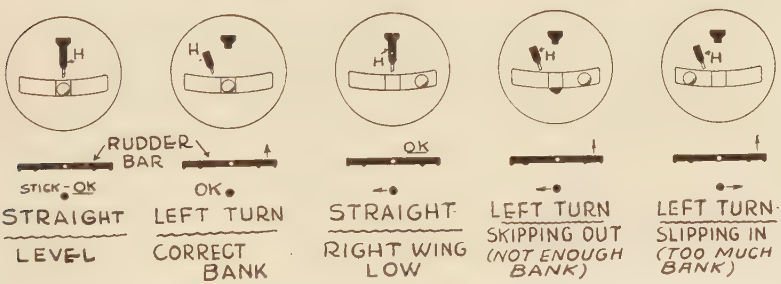


Fig. 107.—Bank indicator during banks and turns.

The bank indicator, which is simply a small steel ball rolling in a tube of liquid and similar to a carpenter's cross level, has not been shown in the drawing of the instrument, but is illustrated in Fig. 107. This is usually incorporated with the turn indicator so as to make one instrument. As long as the airplane is on an even keel, the steel ball will remain in the center of the tube. Banking to the right, without

turning to the right, will cause the ball to roll to the right of the tube, and banking to the left will cause the ball to roll to the left of the tube. The main purpose of the bank indicator is to show the accuracy or correctness of a bank. If a turn and bank are made correctly the ball will remain in the exact center of the tube regardless of the steepness of the bank or the sharpness of the turn. This may seem peculiar, but centrifugal force comes into play again here. If a turn is correctly banked, the banking effect exactly balances the centrifugal force. The same state of affairs exists in the ball tube. The tendency of the ball to roll to one side or the other, owing to gravity, is equalized by the centrifugal effect tending to send it in the opposite direction. Tie a weight to the end of a string and then twirl the string. The weight will fly out and up, overcoming the gravity pull—the same effect is produced on the ball in the tube.

It should be kept in mind that the indication of the bank and turn indicator hand relates to the rudder control, and the indication of the ball to the aileron movement of the control stick. In Fig. 107 the position of the airplane is noted and also the proper movement of both stick and rudder is shown, assuming that it is desired to regain straight and level flight.

Rate-of-Climb Indicator.—A rate-of-climb indicator shows the number of feet that the airplane is climbing or descending per minute. It must not be confused with the *"climb indicator,"* also called an inclinometer, because the latter only shows the *angle* at which the ship is climbing or gliding, while the rate-of-climb instrument shows the *rate* of climb. The airplane's nose may be pointed up very steeply yet the ship be losing altitude. The rate-of-climb indicator would, in such a case, show the rate of loss of altitude regardless of the fact that the airplane might appear as though it were climbing.

It is easier to understand the operation of the rate-of-climb indicator if it is thought of as a leaky altimeter. Assume, for example, that you had an altimeter which had a very tiny leak in the diaphragm. If your airplane climbed to 5,000 feet, the altimeter would indicate about 5,000 feet, but after you stayed at this altitude for some time the indicating hand would return to zero on account of the leak.

Referring to the actual instrument, also manufactured by The Pioneer Instrument Company, and illustrated in Fig. 108, there is a

diaphragm *D,* the inside of which is connected through a tube *E* to the outside of the instrument case. The connection between the inside of the case and the outside air is through a piece of tubing, *C,* having a very small hole, as indicated, which offers considerable resistance to the passage of air. When the airplane is maintaining a constant level and is therefore flying in air of constant pressure, there is no difference in pressure between the outside of the diaphragm (the inside of the case) and the inside of the diaphragm.

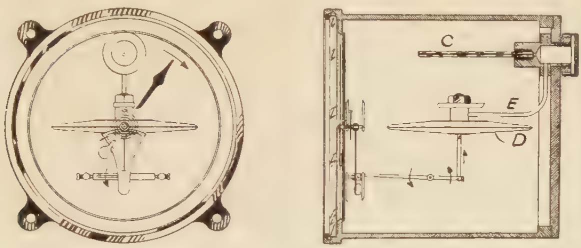


Fig. 108.—Mechanism of the rate-of-climb indicator.

Now suppose the airplane starts to climb, it immediately gets into air which is of a lower pressure than that in which it was previously. This reduced pressure finds its way immediately to the inside of the diaphragm through the tube *E*. The air inside the case, however, is at the pressure corresponding to the previous elevation of the ship and this pressure can only be reduced by the flow of this air through the capillary tube *C*. So long as the airplane continues to climb we have the condition of less pressure inside the diaphragm than outside, because it is never possible for the air in the case to catch up with the outside pressure. This excess pressure outside the diaphragm causes it to collapse partially and the entire mechanism moves in the direction of the arrows, causing the indicating hand to move to the right, and indicating the rate of climb on the dial. The exact amount of difference in pressure inside the diaphragm and inside the case corresponds to the rate at which the airplane is climbing or descending.

Climb Indicator.—This instrument is very simple, performing in a manner similar to a spirit level, the bubble, usually replaced by a steel ball, indicating by its position in the tube the angle at which the plane deviates from the horizontal flying position.

CHAPTER XIV

METEOROLOGY—WEATHER

ALTHOUGH government weather bureaus are at the disposal of airmen when a weather or wind forecast is desired, it is very good policy to have at least an elementary knowledge of weather forecasting in order to recognize the signs indicating the approaching state of the air. Weather conditions can change very quickly and before the time limit of an earlier forecast is reached. Approaching events can be told by conditions arising.

We noted in Chapter III that air pressure varies with conditions. One condition having to do with this variance in pressure is the temperature of the air. Warm air is lighter and exerts less pressure than cold air. Cold air, exerting a greater pressure, tends to squeeze in on warm air, sending it skyward in very much the same manner that water, of great pressure, squeezes in on air bubbles and sends them skyward.

The sun supplies the heat for warming the air. A light-colored object will reflect and throw back light while a dark-colored object will not. Try this experiment: take a newspaper sheet and hold it in front of an automobile headlight some dark night and notice how anyone sitting in the car is illuminated by the reflected light. Then take a piece of dark dull cloth and do the same thing. The dark cloth will not reflect the light.

Heat can be reflected to a great extent the same way and for this reason light-colored ground reflects the sunlight and the sun's heat, warming the air over it and causing an ascending current of air, called a fountain. Conversely, the air over dark-colored ground is cooler and consequently tends to descend, moving over into the space vacated by the warm ascending air. As the cool air travels sideways toward the area of light-colored ground and warm ascending air it creates a current of air called a zephyr, breeze, wind, gale or hurricane, depending upon the speed with which it travels.

Other things cause warm air besides the sun's reflection on light colored ground. The position of the sun in relation to the earth's surface also produces areas of warm air. The tropics are warmer than the arctics. The reflection of the sun's heat from light-colored ground produces more or less local air movement over a not very large area and accounts for the "bumps" and "air pockets" you often hear mentioned in connection with an aërial flight. The bumps are caused by the fountain of warm ascending air striking the aircraft, thus causing it to be carried up with the air current. The so-called pockets, of which there are none, are caused by the descending cooler air striking the aircraft, causing it to be carried down with the air current.

Steady winds are caused by unequal temperatures over large adjacent areas, the velocity of the wind depending upon the difference in temperature between the areas.

The most common and well known of steady winds are called the trade winds which blow in an area extending from 30° north to 30° south of the equator. The commonly accepted explanation of the cause of the trade winds is that the air near the equator is heated and therefore ascends. The cooler air from the two poles, rushing in to fill the space so vacated, causes a more or less steady wind to blow. Regardless of the true reason, we know that these trade winds do blow steadily from the southeast when we are south of the equator and from the northeast when north of the equator.

The reason these winds do not blow directly from the north and directly from the south is that the earth is constantly rotating from west to east. This causes the surface of the earth to slip under the winds, which in reality are blowing directly north and south, but make it appear that the winds come from southeast and northeast.

At a point where the cool air is becoming warmer and starting to ascend, which is near the equator, we find a narrow belt of comparative calm with very little or no wind blowing. This district is called the doldrums.

Just beyond the point where the trade winds begin to gain velocity, in both northern and southern hemispheres, is an area of light, variable winds. This area is called the "horse latitudes," and usually experiences comparatively fresh and clear weather.

Outside of the horse latitude area, all across what is called the

temperate zone, westerly winds will be blowing most of the time but they are often interrupted by occasional shifting and storms. Between 40° and 60° south the prevailing wind is from a general westerly direction. Of course, there are exceptions, but taking the average wind direction for a certain given time, the general movement will be from the west.

A wind known as a periodic wind is one that blows from a certain direction for a given period then changes, or even reverses its direction quite regularly. There are such winds experienced in the China Sea and the Indian Ocean and are there called monsoons. In an area extending from 20° south in Madagascar and Australia to 30° north in India, the wind direction reverses every six months. Difference in temperature of certain areas as well as the rotation of the earth creates the monsoons just as it causes the trade winds.

Land absorbs and rejects heat more readily than does water. When the sun goes down the air cools somewhat, but the earth is still giving off heat to a greater extent than the water which did not become as hot during the day. This creates an ascending current of air over the land, drawing in the cooler air from over the water. This results in the sea breezes felt along the coast of large bodies of water of a summer evening. Just as the earth heats quickly, it cools quickly compared to the ocean. For this reason the ocean retains longer what heat it has absorbed and causes the air currents to flow from the cooler land out over the water and up as the night wears on. This is called a land breeze.

In areas around the Great Lakes, land breezes are the usual form because the comparatively shallow lake becomes heated as the summer advances, retains this heat during the night while the surrounding ground cools.

Variable winds are those that blow without any regularity as to time or place. Sudden storms coming up with very little warning are in this class of wind, and are given names in different parts of the world. They are called the khamsin in Egypt, the norther in Southern United States and the pampero in South America. Light, shifting winds, coming first from one direction and then another, but no direction in particular, are also classed as variable winds.

You have undoubtedly noticed that when a room is warm and the air outside is cold, moisture vapor forms on the inside of the win-

dowpanes. The same phenomena takes place when warm ascending air meets the cool air of the upper atmosphere. The vapor in the warm air is condensed, forming first a white fleecy cloud, and as the phenomena continues, the cloud becomes more and more saturated with moisture until it becomes too heavy to be suspended in the atmosphere and then it falls to earth again as rain. The winds move these clouds about through the sky so that the rain may fall thousands of miles from where it was condensed.

If the actions of warm air ascending and cool air descending were accomplished rapidly it would only take a short time for the temperatures to balance themselves just as hot water poured into cold soon mingles and the whole mass becomes of one temperature, lukewarm. In this case air flow in the form of breezes and wind would soon cease. But the action is more or less slow, being accentuated by the original source of heat.

The warmer areas, with consequent low pressure within them, move about over the surface of the earth. This creates slowly shifting areas of low pressure and of high pressure. The latter, being the cooler descending air currents, usually results in clear, fine weather. As the cool air descends and the warm air ascends, rain clouds are occasionally formed. They move along with the wind toward the area of warm low pressure, usually resulting in unsettled, cloudy or rainy weather.

The ordinary human being is unable to recognize an area of low pressure unless it is very pronounced. You have heard the remark, "It's so sultry and hot—feels like rain." This prophesy is usually correct in such cases. You have also heard the remark, "It was a cold, clear night." It was clear because it was exceptionally cold.

You have also noticed that when a breeze starts, or just before a rain, the air cools somewhat. That is the cool air from outside entering the warm, low-pressure area. The greater the difference in temperature or pressure of the adverse areas, the more likely it is to produce clouds and rain.

The high and low pressure areas all over the world, with the exact amount of pressure in each, are kept track of by the government weather bureaus, and by analyzing the differences in pressures, they are able to forecast the kind of weather to be expected for hours, sometimes days, in advance. In areas subject to steady winds

it is much easier to forecast weather correctly than it is in areas subject to shifting variable winds.

The pressure of the atmosphere is measured with an instrument called a barometer. There are two types of barometers; the mercurial barometer and the aneroid barometer. The mercurial is the more accurate of the two and is one of the instruments used by authentic weather forecasting bureaus.

The mercurial barometer consists of a glass tube about one-third of an inch in diameter, three feet long and closed at one end. This tube is filled with mercury. The open end, which is the bottom of the tube, is a cup or container, and the mercury is allowed to run down out of the tube into the cup until the vacuum above the mercury and the counteracting atmospheric pressure on the exposed mercury in the cup balance each other, causing the mercury left in the tube to remain stationary.

If the pressure on the mercury in the cup were increased it would cause it to rise in the tube, and conversely, if the air pressure were reduced, the mercury would fall.

The outside of the tube is graduated in a scale and vernier of 1/100 of an inch. The thirty-inch point on the scale marks the level of the mercury when it and the surrounding atmosphere are at a temperature of 32° F. Atmospheric pressure is 14.7 pounds to the square inch at 32° F., so this is taken as a datum point, or a base from which to calculate. If the mercury within the tube remained at a constant temperature of 32° F., regardless of the outside atmospheric temperature, accurate readings could be assumed on the graduated scale. But it doesn't. Just as is the case with other material, mercury expands with heat and contracts with cold. For this reason mercurial barometers are provided with a thermometer whose actuating medium is also mercury, so that allowances can be made when an accurate atmospheric pressure is desired.

The aneroid barometer is a mechanically operated indicator of atmospheric pressure. The actuating medium is called a diaphragm. It is a small diameter box with either one or both sides made from thin flexible brass. Some of the air is removed from inside the box, removing much of the resistance to the pressure of the outside atmosphere.

As the atmospheric pressure outside increases, the flexible metal

sides are pressed in, and when the pressure decreases, the sides press outward by their own elasticity, aided by very sensitive springs. Air is removed from the interior of the diaphragm in just the right amount to cause the sides to pause midway in their limits of travel with the atmosphere temperature at 32° F. which exerts a pressure of 14.7 lbs. per square inch. In most respects this instrument resembles the altimeter described before.

The comparatively slight movement of the diaphragm is magnified by a combination of very small levers actuating an index hand which is caused to move either right or left over a graduated scale on the face of the instrument. As in the mercurial barometer, the aneroid barometer scale is graduated in 1/100 of an inch.

The aneroid barometer is not as accurate as the mercurial type but it is of sufficient accuracy to be used by airmen in helping forecast weather. Occasional checking against a mercurial barometer for accuracy is recommended.

"The barometer is falling," or "the barometer is rising," are common expressions heard on shipboard, in weather forecasting bureaus and around airdromes. The former expression means that the atmospheric pressure, and consequently the mercury in the barometer tube, is falling and usually indicates bad weather with wind and possibly rain coming. The latter expression means that the atmospheric pressure, and consequently the mercury in the barometer tube, is rising and usually indicates good, clear weather coming.

As said before, atmospheric temperature, which bears directly on the atmospheric pressure, governs the winds. As we know, air is a fluid and, like water, tends to flow. The direction of air flow will be from a high-pressure area toward a low-pressure area, thus creating wind. The wind so created does not travel toward the low-pressure area in a straight line, however. It leaves the high-pressure area in a general clockwise spiral but, as it flows into the low-pressure area, it reverses direction of rotation to anti-clockwise. In other words, on leaving the high they spiral to the right, and on entering the low they spiral to the left.

The difference between the high and low pressures, together with their distance apart, will govern the velocity of the wind created. For example, a low-pressure area that is not very low and a high-pressure area that is not very high, when far apart, will create very

little air flow from one to the other, but an unusually low area near an unusually high area will create a rapid air flow resulting in winds of gale force.

Change of air pressure in different localities is not always caused by temperature. High and low pressure areas travel across the face of the earth in a manner similar to ocean waves, although not as regularly or uniformly. The atmospheric waves can be compared to high waves, representing the high pressure, low waves representing the low pressure, shallow troughs representing fairly low pressure and deep troughs representing very low pressure. Just as a cork riding water waves will rise and fall, so will a barometer rise and fall when acted upon by such atmospheric pressure waves.

The movement of these pressure areas across the United States is watched and kept track of through telegraphic reports to Washington, D. C., from hundreds of observation points which are located all over the country, in Canada and on ships at sea. These places report the barometric pressure, temperature and wind velocity at that point. It has been found that the general direction of travel taken by the pressure areas is from west to east, passing out into the Atlantic Ocean along the St. Lawrence Valley.

Occasionally a low-pressure area forms in the tropics, passes up the Mississippi Valley or up the Atlantic Coast and then curves eastward after reaching about 30° north latitude.

A chart is prepared from the reports received for the guidance of those interested. This chart is a map of the country with the barometric pressure at the different localities marked on it. Temperature readings are also marked. Then all points having the same barometric pressure are connected with a line, called an isobar, representing lines of equal pressure. All points having the same temperature are connected with a dotted line called an isotherm. The isobars indicate the high and low areas, their closeness to each other and their pressure differences. The wind direction and velocity are indicated by arrows pointing in the direction of wind travel and by the number of arrow points for velocity.

When this chart is so prepared, indicating high and low areas, temperature readings, wind direction and velocity, it is called a weather map and can be obtained, already prepared, from any weather bureau.

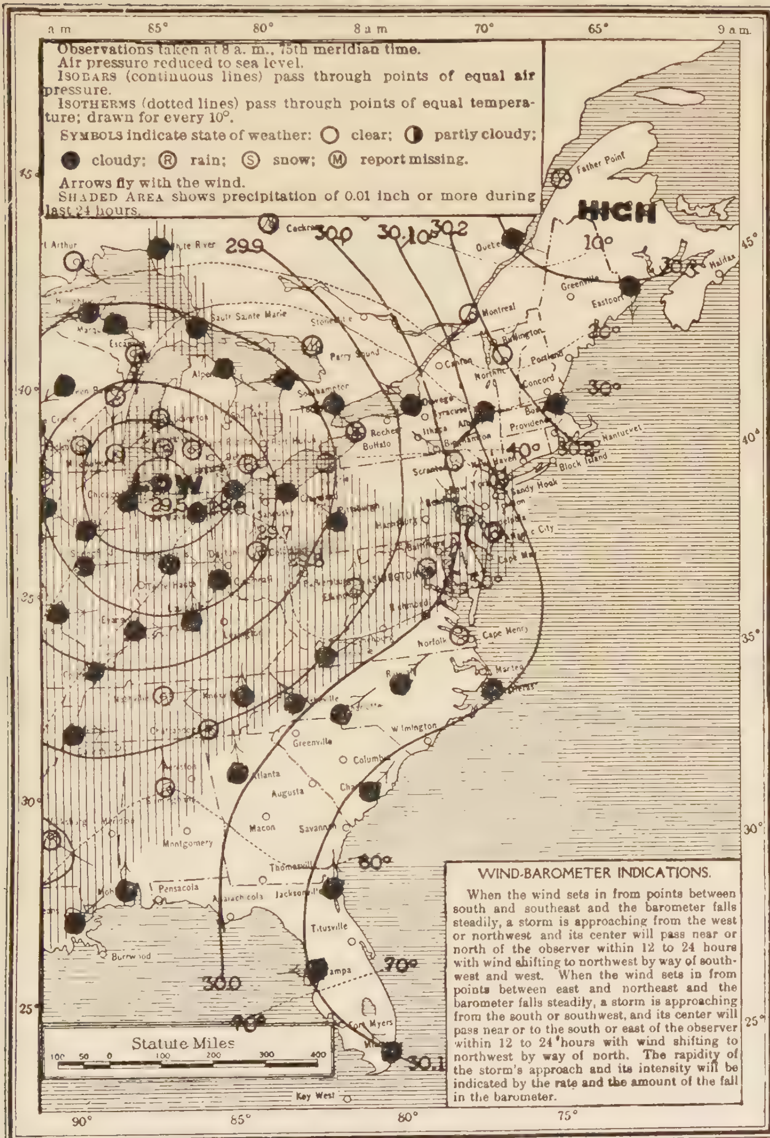


Fig. 109.—Weather Map.

The weather map is very valuable to an aviator, especially if a long cross-country trip is intended. It enables him, with very little study, to know what sort of weather to expect along the route, to avoid bad weather areas, and to take advantage of wind that will help him along. A very little practice will enable the most inexperienced to become somewhat of a weather forecaster.

In flying at an altitude there is one thing must be allowed for but which is not indicated on a weather map. That is the direction and velocity of winds in strata above the ground. The wind direction and velocity indicated on the weather map are those of the surface wind. Above three or four thousand feet the wind direction changes to a point about 20° clockwise to that of the wind on the ground. The velocity increases somewhat. At a still higher altitude the wind direction may completely reverse itself, or it may be blowing from a point 90° away from that of the surface wind. This can only be ascertained while on the ground by releasing small balloons, watching their direction and speed of travel as they pass through different wind strata. This check is made two or three times a day at an established airport of any size and at government weather bureaus.

Besides a study of the weather map there are other ways of forecasting the approximate weather. One of these ways is by the appearance of the sky and by bird action.

If sea gulls are noticed resting ashore in large numbers, or flying over inland lakes, it is usually an indication of a strong wind or a storm approaching.

Delicate, soft appearing clouds indicate a light breeze and fine weather.

If the sun sets in a blaze of red it means good weather next day.

If at sunrise, or for several hours thereafter, the sky is red it means bad weather with probable wind and rain.

A gray morning sky indicates good weather.

If at sunset the sky is bright yellow, a wind may be expected—if of pale yellow color, rain.

Clouds with heavy edges and oily appearance indicate wind.

A light blue sky foretells fine weather.

As a general rule the softer the clouds appear, the less wind; the more ragged, greasy and hard they appear, the greater the wind.

You have possibly heard the following rhymes about the weather, they contain good forecasting wisdom and when applied are very seldom wrong.

Long foretold, long last,
Small warning, soon past.

* * *

Evening red and morning gray,
Both are signs of a very good day.

* * *

Red sky in the morning,
Sailors take warning,
Red sky at night,
Sailors delight.

* * *

Seagull, seagull, sitting on the sand,
It's never good weather when you're on land.

* * *

To assist those in need of weather information, but either too busy or unable to forecast for themselves, signal flags have been devised; their color, insignia and manner of flying indicating the kind of weather approaching. They will be found flying at weather bureau buildings, coastal lighthouses, harbor offices and modern airports.

A square flag with a black square center on a background of red indicates a violent storm is expected.

A triangular red pennant flown above the storm flag indicates a northeast wind; flown below the storm flag, a southeast wind.

A triangular white pennant flown above the storm flag indicates a northwest wind; flown below the storm flag, a southwest wind.

A triangular red pennant flown alone indicates the approach of a moderate storm.

When two storm flags are displayed, one over the other, it indicates the approach of a hurricane.

If a through plane is expected to pass over an airport and those on the ground have received word of approaching unfavorable flying weather, a red fusee, or its equivalent, is displayed.

If two red fusees, or their equivalent, are displayed it is a definite signal to the airman that he should not proceed farther but should land.

Wind Indications.—Here is a table, called the Beaufort Table used to designate winds. Weather maps indicate the velocity of the wind by a number, not by the speed of the wind itself, and these numbers will be found in the left hand column.

NO.	NAME	GENERAL OBSERVATION	SPEED ON GROUND
0.	Calm	Smoke rises vertically, flags hang limp.	Less than 1 m.p.h.
1.	Light air	Direction of wind can be noted by smoke but not by wind vanes—cone will indicate lazily, flags by slight movement.	1— 3
2.	Slight breeze	The wind can be just felt on the face. Tree and bush leaves just rustle, cone stands at about 10°, smoke will float off with wind.	4— 7
3.	Gentle breeze	Leaves and small twigs on trees in motion most of the time.	
4.	Moderate breeze	Dust will rise and loose paper will move about. Small branches on trees will move.	13—18
5.	Fresh breeze	Small trees with leaves will begin to move and sway. Slight whitecaps will be seen on lakes.	19—24
6.	Strong breeze	The larger branches of trees will be in motion. Telegraph wires will begin to whistle. An umbrella might be turned inside out.	25—31
7.	High wind	Ordinary size trees in motion. Rather hard to walk against wind. Cone and flags out straight.	32—38
8.	Gale	Twigs will be broken off trees. Necessary to lean against wind while walking. Flags whip badly.	39—46

9. Strong gale	Loose chimneys blow down, air filled with dust, paper and other débris. Loose signs blow down.	47—54
10. Whole gale	A wind of this velocity is very seldom felt inland, but if so whole trees might be blown down and considerable damage done to buildings.	55—63

CHAPTER XV

AËRIAL NAVIGATION

NAVIGATION is the art of following the most direct route, of calculating distance and of finding the exact location of a ship at sea or an airplane over land or sea, with the aid of certain instruments. The word "navigation" has been in use for hundreds of years in relation to boat guidance, but the advent of airplanes and airships has caused another word to be coined and included in the dictionary. The later word is "avigation" and means the navigation of aircraft. A great many basic principles of avigation have been taken from navigation, and now navigation is beginning to learn things from avigation.

The main object of avigation is to enable one unerringly to fly a predetermined route, or course, as it is called, between two or more points over territory unfamiliar or out of sight. It is not well to rely upon the human sense of direction to accomplish this, so use is made of instruments that operate according to certain positive principles. The most common and familiar of these instruments is the magnetic compass.

Before one can understand avigation or navigation it is necessary to be familiar with the basic facts upon which the study is founded. The most important of these facts are the divisions of the earth's surface and how a compass works.

Boxing the Compass.—Everyone knows that there are four major directions, North, South, East and West. For avigation these four major directions are further divided into a total of thirty-two directions, and then each one of the thirty-two directions is called a "point" on the compass. Each one of these directional points has a name as well as a designating number, and the names should be learned in the order of their location, starting at the North and proceeding around by way of East until the North is reached again. The directional points named in this order as shown in Fig. 110,

are: NORTH, north-by-east, north-northeast, northeast-by-north; NORTHEAST, northeast-by-east, east-northeast, east-by-north; EAST, east-by-south, east-southeast, southeast-by-east; SOUTHEAST, southeast-by-south, south-southeast, south-by-east; SOUTH, south-by-west, south-southwest, southwest-by-south; SOUTHWEST, southwest-by-west, west-southwest, west-by-south; WEST, west-by-north, west-northwest, northwest-by-west; NORTHWEST, northwest-by-north, north-northwest, north-by-west, NORTH. Naming the directional points of a compass in this manner is called "boxing the compass."

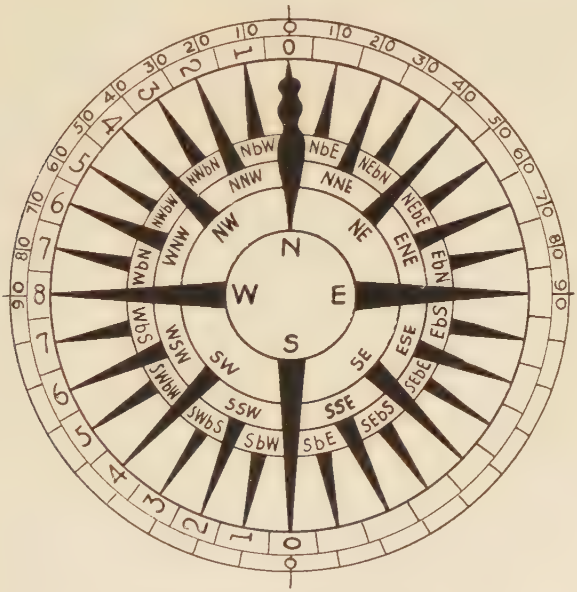


Fig. 110.—Marine compass card.

Point Numbers.—North, East, South and West are called the cardinal points; Northeast, Southeast, Southwest and Northwest are called the intercardinal points. By studying the compass card of Fig. 110 you will notice that each cardinal point is eight points away from the other nearest cardinal point and four points away from the nearest intercardinal point. A line running straight

through a compass card from the North point to the South point is called the meridian, and all courses are figured, or reckoned, from the meridian line.

The illustration, Fig. 110, shows a compass card used on boats. The aviation compass card is somewhat different, but in order to understand the markings of the aviation compass it is necessary to be familiar with the boat compass card. You will notice that each directional point is numbered, not consecutively all around the circle, but by eights east and west from the North, and east and west from the South. This is done to make the indication of any one direction easier than by naming it. It is easier to say and be unmistakably understood, "five points west of north" than it is to say "northwest-by-west."

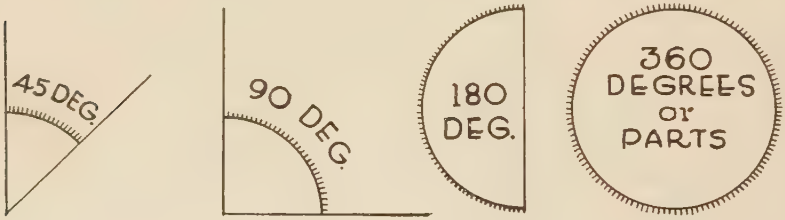


Fig. 111.—Degrees of a circle.

Degrees.—The compass card is also marked off in degrees. Every circle, no matter how large or how small, can be divided into three hundred and sixty equal parts. If you cut a pie into three hundred and sixty equal wedge-shaped parts, the angle between any two adjacent cuts would be a one-degree angle. A watch face is divided into sixty equal parts called minutes, but when measuring degrees on that same watch face, it is divided into three hundred and sixty equal parts and then called degrees. Fig. 111 illustrates different parts of a circle and the number of degrees contained in each part. The full circle contains the complete three hundred and sixty degrees. The next figure to the left is only half a circle, so contains only half as many degrees, or one hundred and eighty. The third figure from the right is only one-quarter of a complete circle and so contains only one-quarter of the total number of degrees, or ninety degrees. The extreme left hand figure is one-eighth of a complete circle, contains one-eighth of three hundred and sixty

degrees, or forty-five degrees. If the lines shown dividing the degrees were lengthened for any distance whatever the degree of angle would remain the same. This holds true whether you consider the round face of a watch or the face of the earth, the divisions of the circle remain the same.

The compass card is a circle, and in addition to being marked with the direction names and numbers, it is also marked in degrees. The conventional boat compass card is not marked with the full three hundred and sixty degrees consecutively, but for ninety degrees only, starting at the South and counting east and west, and starting at the North and counting east and west. This brings the ninety degree mark to the East and to the West. Direction can then be designated in compass degrees as well as direction name or point number.

Longitude and Latitude.—Everything in the world is measurable, the unit of measure differing with that which is measured. The inch, foot and yard are the most common units of length, but things impossible to measure with these are divided and measured in other ways. Liquid is measured by the quart, gallon, etc., grain by the peck, bushel, etc. The surface of the earth is also measured by imaginary divisional lines running from the south pole to the north pole, and by others running around the earth parallel to the equator. The lines running north and south are called meridians, and the lines running east and west are called parallels. Each one of these meridians and parallels has an identifying number corresponding to the degrees of a circle. There must be a starting point for this numbering, and for the meridians it is a line starting at the north pole, running down through the North Sea, touching the southeastern tip of Great Britain, the Greenwich Observatory, through the center of France, eastern Spain, through the center of the Sahara Desert in Africa, into the Antarctic Ocean and so to the south pole. This longitudinal datum meridian is designated as Greenwich in Fig. 112.

There are three hundred and sixty imaginary meridians on the earth's surface, these being numbered east and west from Greenwich until the one hundred and eightieth meridian is reached, or exactly halfway around the circumference of the earth. This makes one hundred and eighty degrees east of Greenwich and one hundred

and eighty degrees west of Greenwich. For a simple illustration, note the lines ten degrees apart in Figs. 112 and 113.

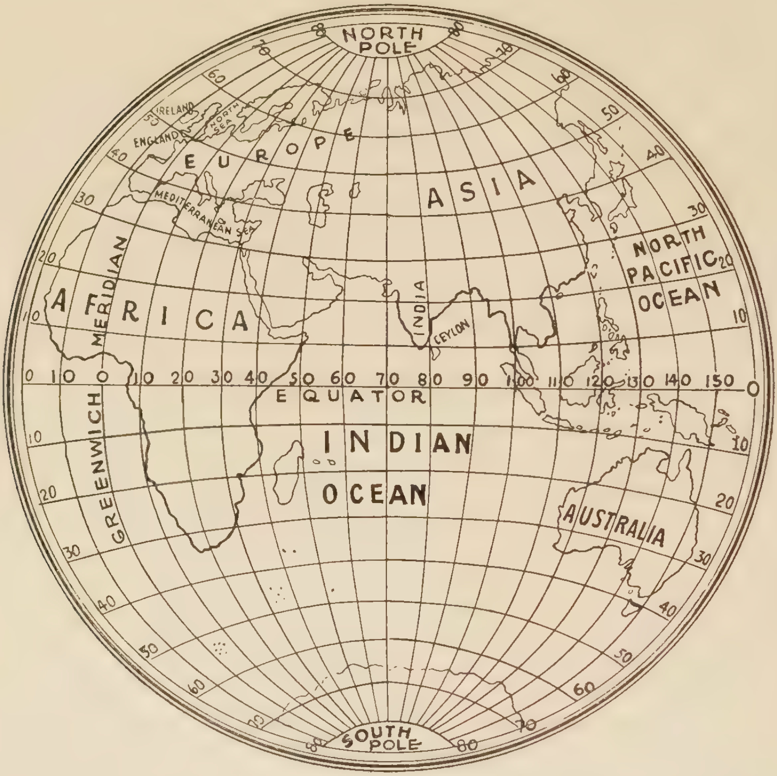


Fig. 112.—The Eastern hemisphere showing the Greenwich meridian.

The datum, or starting line, for the parallels is an imaginary line running around the earth from east to west at its greatest circumference, called the equator. The parallels are numbered up to ninety degrees, north and south of the equator. This is illustrated in Fig. 112, the ninetieth parallel being the north or south pole. The meridians are designated as being east or west of Greenwich, thus; fifteen degrees west of Greenwich; forty degrees east of

Greenwich, etc. The parallels are designated as being north or south of the equator, thus; thirty degrees south; twenty degrees north, etc. The degrees of both latitude and longitude are further divided into smaller units of measure, each degree being divided into sixty equal parts called "minutes," and the minutes in turn are divided into sixty equal parts called "seconds." In this way it is possible to designate very definitely any particular spot on the earth's surface, as, thirty degrees, forty-two minutes and thirty-six seconds west; ten degrees, twenty minutes and fifty-eight seconds south. If you had a chart of the earth marked with these measurements you would find this designated spot somewhere in the south central part of Africa. One minute of earth measurement is equal to one nautical mile. The nautical mile is slightly longer than a land mile, 6,086 feet, to be exact. One second of earth measurement equals a little over 101 land feet, so you can see that using latitude and longitude supplies a fairly accurate system of measurement.

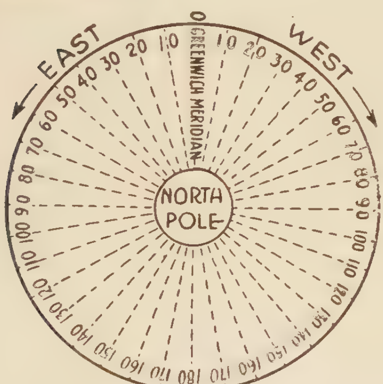


Fig. 113.—How the meridians radiate from the poles.

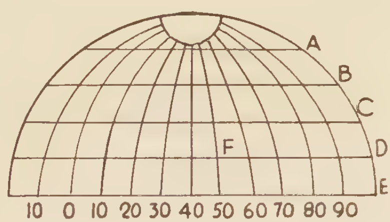


Fig. 114.—Meridians vary in distance apart; parallels remain the same.

One minute of longitude is exactly one nautical mile at the equator only, because the meridians come together at the poles. One minute of latitude is always one nautical mile because the parallels remain the same distance apart all the way around the earth. This is illustrated in Fig. 114, which can be considered a profile of the

earth cut in two at the equator. The distance from *D* to *F* would always be the same in degrees, minutes and seconds whether measured on latitude *A, B, C, D* or *E,* but it would not be the same number of miles because the meridians *0, 20, 30,* etc., come closer and closer together in miles as they near the poles. The distances in miles between the parallels *A, B, C,* etc., remain the same on any meridian, however, because these lines are parallel, keeping the same distance apart all around the circumference of the earth.

The degree, minute and second method of measurement is used because of the earth's huge proportions. If locations were designated by miles in a certain direction from some other place it would result in a hopelessly mixed up affair if applied to navigation. For example, looking at Fig. 112, suppose we wished to reach the northern point of Ceylon. Instead of saying that it is so many miles off the southern point of India, which at best is a very vague designation, we would say that it is eighty degrees east, ten degrees north, meaning that it lies at the intersection of the eightieth meridian east of Greenwich and the tenth parallel north of the quarter. The exact location would then be simple to find by referring to a chart, or map, of the eastern hemisphere.

The parallels and meridians can be accurately located on the earth's surface by the use of an instrument called a sextant which measures the angle of heavenly bodies such as the sun, moon and stars, in relation to the earth. Using this instrument and the accompanying system is not necessary except when flying over water and out of sight of land for hours at a time. For ordinary flying avigation, direction only is necessary and can be followed with the use of a compass and other simple instruments.

Operation of the Magnetic Compass.—Electrical lines of force are continually traveling from the earth's north pole to the south pole in much the same manner as electrical lines of force travel from pole to pole of a magnet. The earth is really a huge magnet with two poles, one called the north pole and the other the south pole. The north pole is the positive and the south pole is the negative. We know that electricity flows from the positive pole to the negative pole, therefore there are electrical lines of force continually flowing between the poles of the earth, as illustrated in Fig. 115. These lines of force operate the compass.

In the ordinary magnetic compass there are several steel needles, slightly magnetized, placed parallel to each other and mounted underneath the compass card. The north and south meridian of the card is oriented to lie exactly parallel to the needles. As we know, positive attracts negative and the needles each have a positive pole and a negative pole. The negative poles of the needles are attracted by the earth's positive pole, north, thus causing the compass card to point to the magnetic north.

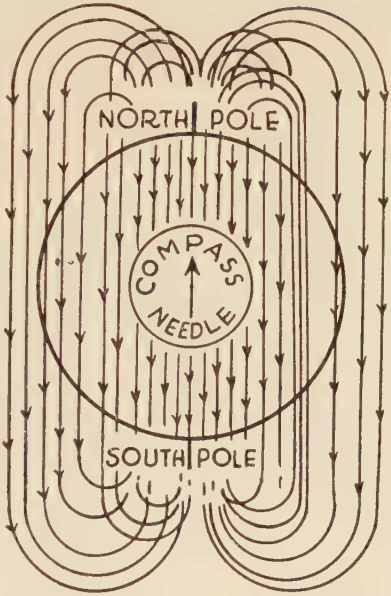


Fig. 115.—The earth's magnetic field.

The compass card with the attached needles is then mounted on a float, similar to a carburetor float, for instance, and placed in a case containing a non-freezing liquid. Using liquid reduces friction to the least possible amount as the card and float turn in the case.

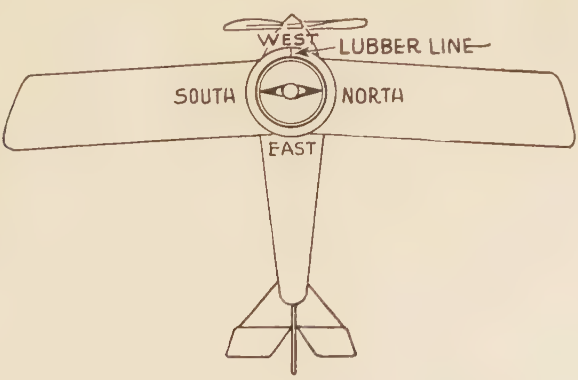


Fig. 116.—Exaggerated compass mounted on plane and showing lubber line.

On the outside of the compass case is a mark called the "lubber line" which is always pointed toward the exact front of the ship, as illustrated in Fig. 116. The compass case is fastened solidly to the ship and in consequence the lubber line will change position in relation to north or south as the ship changes direction, but the compass card and needles will continue to point north. By noting the direction indicated by the compass card which is in line with the lubber line, it is instantly apparent in what direction the ship is flying. As illustrated in Fig. 116, the ship is flying directly west because, although the card needles are pointing north, the lubber line is opposite the "west" marking of the card.

Variation.—These are errors in the magnetic compass which inject some difficulties into laying a course to follow. There are in reality two north poles and two south poles. The exact point on the earth's uppermost surface where the center of electrical attraction is located is not the true geographical apex of the earth. It would simplify navigation immensely if this center of electrical attraction, called the magnetic north pole, would stay in one exact spot indefinitely, but it doesn't, it moves around over a period of several years. If it were permanent, longitudes and latitudes could be figured from it and centered at it. This movement of the magnetic north pole is kept track of by scientists, so we need not worry about it except that we must consider it when figuring what direction to put on the lubber line for a geographic course.

Navigating charts are marked with the magnetic north pole position noted at different points on the earth's surface. At a few places on the globe the compass will point directly at both the magnetic and geographic north pole; this is when both are in line with each other. When there is a difference between them it is called "variation." The compass is all right and points to the magnetic north pole, but this is not the exact north end of the earth's axis.

On all navigation maps, or charts, as they are called, you will notice a line running from north to south and on these lines there will be notations such as "10° W," or "15° E." These notations mean that the magnetic north pole, at this point, is ten degrees west or fifteen degrees east of the true geographic north pole, as the

case may be. To understand how this variation must be allowed for when figuring what compass course to fly, look at Fig. 117. The inner circle represents the compass card and the outer circle the horizon. The variation in this case is eleven degrees and fifteen minutes or one complete point, westerly. Therefore the compass needle is pointing north-by-west geographically. If you stood in the center of the circle you would see that every point of the compass is exactly one point to the left of the place that it should be. So if the compass in this case indicated that you were traveling north, you are actually traveling geographically north-by-west. If you desired to travel geographically north then, you would steer the plane so that the eleven-degree-fifteen-minute east, or north-by-east mark, was in direct line with the lubber line.

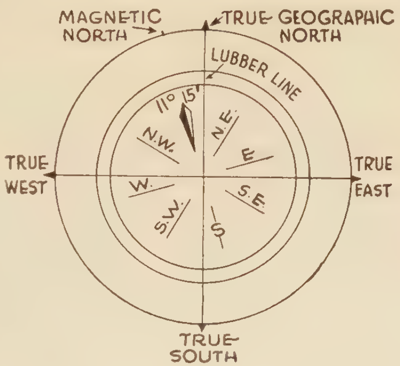


Fig. 117.—Allowing for variation.

Sometimes the variation is easterly, it depends upon where you are on the earth's surface. A good rule to remember is: when the variation is westerly, your course will be as many points easterly as the variation is westerly. When the variation is easterly, your course will be as many points westerly as the variation is easterly. In other words, when variation is westerly, the compass course should be to the right of the true course; when variation is easterly, the compass course should be to the left of the true course.

Deviation.—The ordinary magnetic compass is subject to errors, variation being one of them. Another error is called deviation. Deviation is caused by local conditions in the aircraft on which the compass is used. Iron and steel contain a certain amount of magnetism; the magneto is generating electrical current, forming more magnetism. This magnetism influences the compass needles to a certain extent, pulling them to one side or the other, depending upon which side the pull is located. In ships built with a great deal of iron or steel, the influence is quite pronounced and a magnetic

compass used on a plane of this construction is never exactly correct.

Because of the fact that the compass card and needles do not turn with the plane, the magnetized metal in the plane assumes a new position in relation to the compass needles each time the direction of flight is altered. Suppose, for instance, that you were flying due north, the mass of metal in the engine is directly in front of the compass needles and exerting some pull on it in this direction. Now suppose that you turn and fly due west. The compass card and needles are still pointing due north, but the mass of metal has been moved around until its effect is being exerted on the left side of the needles and tending to attract them slightly westward. This fact is what makes allowing for deviation very troublesome when flying a course. This error is overcome to a certain extent by "compensating" the compass for each individual ship. The work of so compensating a compass is called "swinging the ship."

Swinging the Ship.—To properly compensate a compass it is first necessary that the compass be mounted so that it can be read easily but also so it is as far away as possible from iron and steel parts. It is very desirable to place the compass on the center fore-and-aft line of the plane. To completely compensate a compass is often a long and tiresome job, and is very seldom necessary except on planes intended for exceptionally long flights. Ordinarily it is enough to compensate the compass to within one or two degrees of the true magnetic heading on the cardinal points, North, South, East and West. The error occurring on the other headings can be noted on a card hung near the compass and allowance made in setting the course. The ordinary compensating adjustment is not difficult and can be made quickly.

Different methods can be used in determining the true magnetic directions, depending upon local conditions and the type of airplane. One method is to clear off a level space on the flying field large enough for the plane to be turned around in a complete circle. A flooring of level planks is helpful but not absolutely necessary. The spot picked for swinging should be far enough away from masses of metal or electrical influences to insure the compass needles from being affected in any way. Large commercial airports usually keep on hand an aperiodic compass, a superaccurate instrument,

with which to check the accuracy of other compasses. When the aperiodic compass is available it is best to use it in laying out a true north and south meridian and also to check the accuracy of the ship's compass before swinging. If the aperiodic compass is not available the ship's compass can be used. It should be placed in the center of the cleared space and the needle allowed to come to a complete rest. Then run a stout string several feet longer than the ship, having a stake attached to each end, parallel to the north and south magnetic meridian as indicated by the compass. This is done by sighting along the string and compass card. Drive the stakes in the ground so that the string is drawn taut. Do the same thing for an accurate magnetic east and west line.

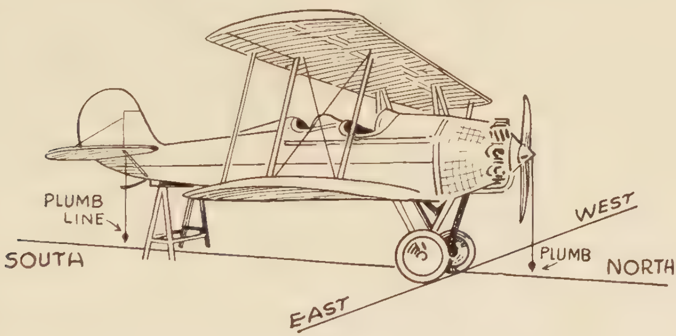


Fig. 118.—Swinging a ship.

Then mount the compass in the ship so that its lubber line is pointing directly to the front. It is very important to set the instrument accurately in this respect. Then attach plumb lines and bobbins to the center datum points on the ship, one at the extreme nose and the other at the extreme tail. Place the ship over the north and south line on the ground so that the bobbins are directly over it. The ship is then heading true magnetic north regardless of what the compass indicates. The compass card may indicate that the ship is slightly off the true north. If so, it is due to the metal in the plane influencing the compass, and the amount off is the deviation of the compass on this heading.

Compensation.—In all navigation compasses arrangements have

been provided to compensate for deviation. The usual manner is to place small magnets of the proper strength on the side of the needles toward which it is desired to draw them. If the card has swung slightly east after having been placed in the ship, a compensating magnet is placed on the west side to pull it back to the true magnetic north. Different strength magnets are tried until the card is resting in its proper place.

After compensating for north, the ship is swung around so that it heads magnetic east, ascertaining the position by the same plumb line and bobbin method used in heading it north. If the compass reading is incorrect when heading east, more compensating magnets are properly placed to correct it. The operation is then repeated with the plane heading south and west, but if compensation is required on either of the last two headings, it means reducing the strength of the compensating magnets already placed, and, of course, will throw the compass out of adjustment for the north and east headings. For this reason only half of the compensating magnet's strength should be removed and thus leave the errors on opposite headings approximately even. So even after a ship is swung the compass still may not indicate the true magnetic points of the compass. Whatever error still exists should be noted on the error card already mentioned.

The ship is then swung on the four intercardinal points of direction; Northeast, Northwest, Southwest and Southeast. The errors occurring on these headings are noted on the error card, but compensation is not attempted because the accuracy on the other headings would be disturbed. How to figure and allow for deviation errors will be explained later when plotting a course.

Other Errors.—While in the air the magnetic compass is only correct when the plane is on an even keel and flying straight. As the plane banks the compass card banks with it and while in this position the needles are affected by the change in the direction of the lines of force of the earth's magnetic field. The slight friction of the card and float will also affect the movement of the card. It is built to float free when horizontally level only. The errors of the compass increase rapidly as the banking angle is increased, a bank of twenty degrees being sufficient to completely destroy its accurate working. This condition is found in any compass that

depends upon the earth's magnetic field for its directive effect and upon gravity for keeping it stable.

The compass reading will be thrown off slightly while turning because the card too will attempt to turn in the case. Sometimes as much as thirty seconds is required for the card to stop swinging back and forth and come to rest. Therefore when it is desired to take a compass reading the plane must be flying straight and on an even keel.

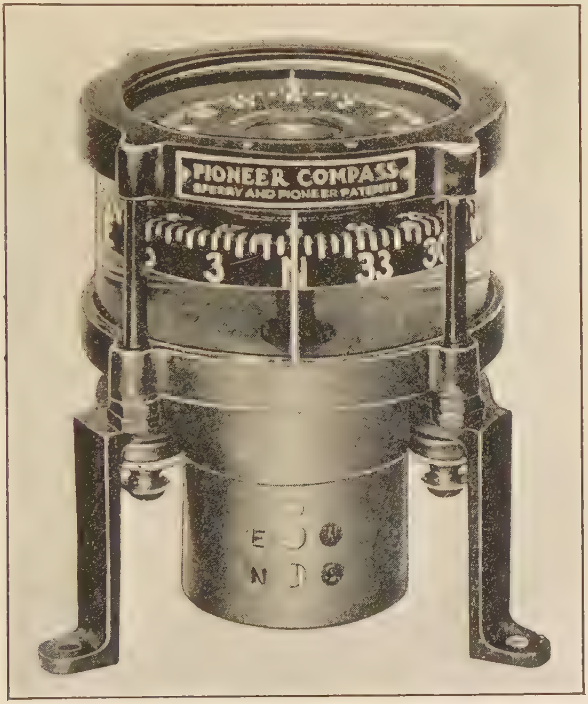


Fig. 119.—Magnetic aviation compass.

Aviation Compass Markings.—On the Pioneer Instrument Company's airplane compass, Fig. 119, as on several others, the card can be viewed from the side as well as from the top. The card is not marked with all of the direction points, only the cardinal points

being so indicated. The rest of the points are marked in degrees, starting with zero for North, and proceeding around the card eastward, graduated every five degrees, ending with three hundred and sixty degrees at North again. Every thirty degrees between the cardinal points, which are marked with the letter indicating the point, is marked with figures. The figures, however, indicate one-tenth of the actual degrees and a cipher must be added to the number to read correctly. Thus, in Fig. 119, you will see the figure "33" just west of North (N) and adding a cipher indicates 330 degrees east of North. Just east of North you can see the figure "3," adding the cipher indicates 30 degrees east of North. This plan of marking is carried out all the way around the card, from North in a clockwise direction. The intervening graduations of five degrees are marked with a plain white line. It is very necessary to keep this marking system in mind so that when reading an aviation compass you can instantly translate the figures into either direction or degrees from the North meridian. This manner of marking is used so that the readings can be printed larger and easily read.

Earth Inductor Compass.—Due to the many errors affecting the operation of the ordinary magnetic compass, especially on airplanes, the "earth inductor" compass was invented by the late Morris M. Titterington, chief engineer of the Pioneer Instrument Company. It was used by the U. S. Army on their 'Round-the-World and Pan-American flights, on Commander Roger's Hawaiian flight, Commander Byrd's North Pole flight, on the transatlantic flights of Lindbergh, Chamberlain and Byrd and on the flight of Brock and Schlee from New York to Tokio.

The earth inductor compass is a remote indicator of direction; that is, the operating part can be placed some distance from the indicating part. It is related to the ordinary magnetic compass only in that it uses the earth's magnetic lines of force as a directing medium.

The earth inductor compass is made up of three principle units or parts. That part which reacts to the earth's magnetic field, and therefore corresponds to the magnetic needles of the ordinary compass, is the inductor generator, shown in Fig. 120. This resembles an ordinary electric generator except that it has no artificial field but uses the earth's magnetic field only. It has an armature, com-

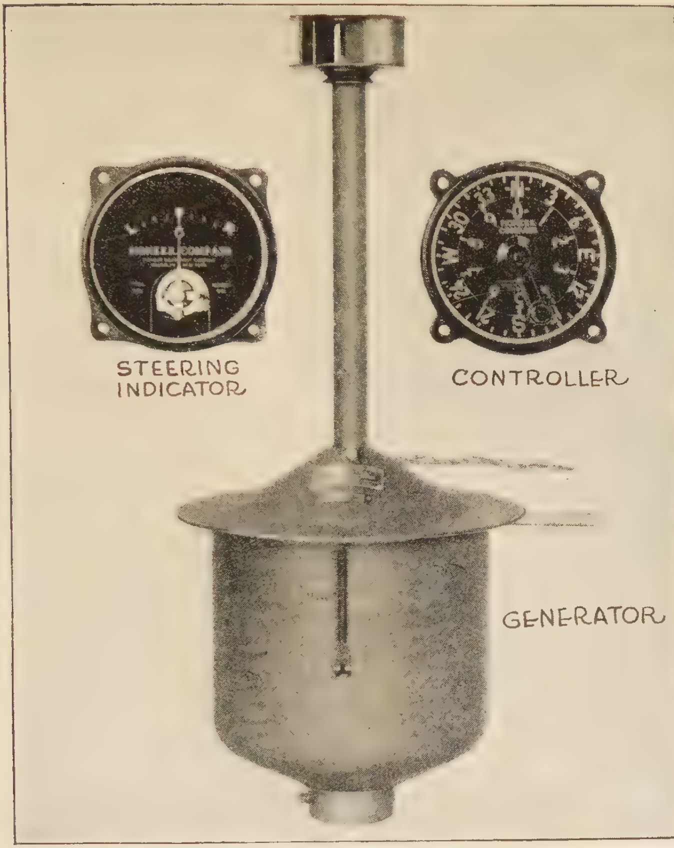


Fig. 120.—Units of the earth inductor compass.

mutator and brushes and produces electric voltage by reaction with the earth's magnetic field. The armature is rotated by a small windmill mounted on top and placed in the propeller slip stream. The voltage depends upon the angle between the brushes and the earth's field. The brushes may be moved about a vertical axis, through a controlling device, so that they may be set in any angular relation to the fore-and-aft line of the airplane. They may be turned, therefore, in relation to the earth's field, either independently or with

the airplane as it turns. As in any generator, turning the brushes in relation to the field would show two positions of maximum potential and two positions of zero potential. In the earth inductor compass use is made of one of these positions of no potential.

The second part of the compass is the direction controller. This carries a dial similar in appearance to an ordinary compass card and has a crank by which the dial may be turned to any desired position. There is a mechanical connection between the controller dial and the brushes of the generator so that the angular position of the brushes is shown and indicated upon the controller dial.

The third part of the compass is the steering indicator. It is a sensitive zero-center galvanometer (corresponding to a turn indicator), the dial of which is marked *L* for left and *R* for right. This indicator is electrically connected to the generator brushes by wires.

When the compass is installed, the connection between the controller and the generator is made such that when the airplane is headed in the direction indicated on the controller, the brushes will be in a position of zero potential; in other words, the armature axis and brushes are parallel to the earth's lines of force and no current is being generated. Therefore the steering indicator hand will remain in the center of the dial as in the illustration. If the airplane is turned to the right the generator brushes will be turned in relation to the earth's field and the generator will then produce electricity of the proper polarity and potential to cause the hand of the steering indicator to move to the right, thereby showing the pilot that the airplane has turned to the right off its course. Turning the airplane to the left will put the generator brushes into such a position that electricity of the opposite sign is generated, thereby causing the steering indicator hand to move to the left.

As the compass is ordinarily used the desired direction heading is set upon the dial of the controller by moving the crank, thus moving the generator brushes into position paralleling the earth's field when the plane is headed in the desired direction. The airplane is then turned until the steering indicator hand comes to zero or straight up. Turns to the right or left of this heading will cause the hand to move right or left. When it is desired to change heading or direction, the controller dial is moved by the crank until the desired

direction marking is brought under the white line shown over *N*. The airplane is then turned to bring the steering indicator hand straight up.

The earth inductor compass offers many advantages over the ordinary magnetic compass, particularly for use on aircraft. It is much easier to follow the hand of the steering indicator with the eye than it is to keep a certain mark on a swaying compass card opposite the lubber line. The outstanding advantage, however, is the separation of the direction finding part, the generator, from the direction indicating part, the indicator. In the ordinary magnetic compass these units cannot be separated and in order that the pilot may see his compass, it is very often necessary to place it in a position where it is subject to strong local magnetic influences causing deviation. With the earth inductor compass the generator may be placed in a position which is practically free from such influence, such as the extreme tail of the plane, while the indicator can be placed in the best possible position for observation. The controller can be operated either by the pilot or by a navigator in another part of the ship.

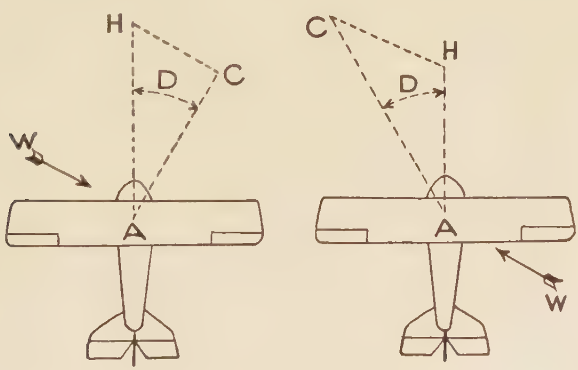


Fig. 121.—Drift of a plane.

Drift and Speed Indicator.—Drift is another error, common to both navigation and avigation, and is just what the name implies—drifting sideways off the course. This error is called leeway when applied to boat navigation. It is caused by the wind striking an

airplane at some angle other than straight head on or tail on. An airplane may be headed in one direction yet be blown sideways over a course in another direction. The difference between the *heading* and the *actual course* being traveled is the drift angle. This is illustrated in Fig. 121. The airplane *A* is headed in the direction *H*, but because of the sidewind *W*, is actually traveling toward *C*. Therefore the angle *D* is the drift. These side winds are not accounted for nor compensated for in any type of compass. In order to fly the desired course accurately, different methods are used to find out the amount of drift that the plane is being subjected to. A common method is to drop smoke bombs and note the direction of the smoke as the wind blows it away. Dust on the ground, trees blowing, smoke from factories, flags, and water waves, will all indicate the direction and approximate velocity of the wind on the ground, but is not always an accurate indicator of the plane's drift because the wind might be blowing in another direction at the altitude at which the ship is flying. If accurate aërial navigation is to be accomplished, it is necessary that the pilot or navigator know the drift angle so that the heading may be corrected and the plane steered accordingly.

The most accurate method of ascertaining this drift angle is by observation of the ground through an instrument called a drift indicator, or drift angle meter as the instrument is sometimes called. It is illustrated in Fig. 122.

The instrument consists of a frame holding a wire perfectly straight and taut. This wire is called the drift wire. The drift wire frame is mounted on a movable vane to which is attached the eyepiece holder and hooded eyepiece through which to take the observations. The vane is pivoted and a pointer is attached that moves over a drift angle scale.

The instrument may be mounted anywhere on an airplane where an unobstructed view downward is possible—vertical is best but at an angle if more convenient—and where it may be conveniently observed and manipulated by the navigator. The instrument is supported by a mounting bracket from which it can be quickly removed. There are sometimes several such brackets mounted on the airplane to which the instrument may be transferred according to the direction of drift or the convenience of the navigator. The bracket

must be installed with its center line either directly fore-and-aft or directly crosswise of the ship. Any error in so installing will cause a corresponding error in drift readings.

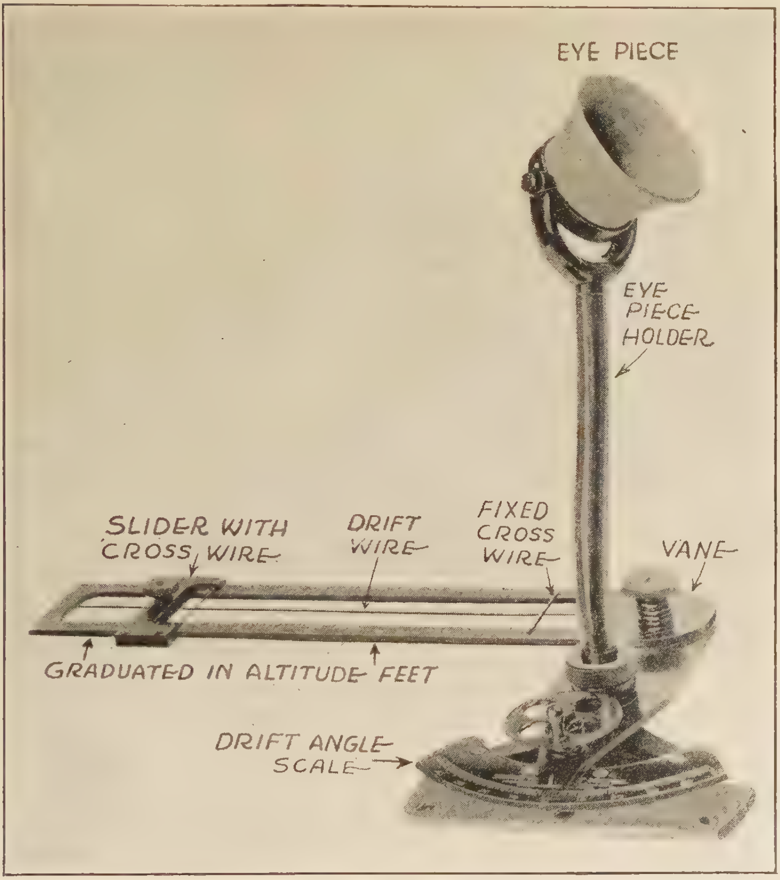


Fig. 122.—Drift angle meter.

To obtain the drift angle with this instrument, first make fast the eyepiece support in a position which will be convenient for the user and which will also allow him to make the observations properly.

It is not necessary that the eyepiece be directly over the drift wire. The operator then sights through the eyepiece at the drift wire and at the same time the ground below. The vane is then rotated until objects on the ground or sea appear to travel on an exact line with the drift wire. This results in the drift wire being in line with the actual course being followed in respect to the ground, regardless of what direction the plane is heading. Rotating the vane has caused the pointer to move over the scale to a graduation mark that will indicate the angle of drift, or the angle between the heading of the plane and the course being actually flown over the ground.

The instrument can also be used accurately to show the ground speed of the plane, by leaving the vane in the position corresponding to the drift angle and move the slider and cross wire on the frame until the cross wire is at the figure corresponding to the altitude of the plane above the ground over which it is flying. The altitude of the country underneath must be subtracted from the altitude of the plane above *sea level* to obtain the actual altitude of the plane above the ground.

Looking through the eyepiece, the distance seen on the ground is that marked on the side of the vane—either one-tenth mile, four-tenths mile, or one mile. The scale which reads "One mile for altitude in thousand feet" can also be used for "One-tenth mile for altitude in hundred feet."

With a watch, time the passage of an object from one wire to the other, then refer to the table furnished with the instrument which gives the corresponding speed in miles per hour. For example, suppose that it is desired to obtain the ground speed while flying at an altitude of 4,000 feet above the ground. First, move the slider along the drift wire frame and set the cross wire at the figure "4," which is on the scale marked "Four-tenths mile for altitude in thousand feet." Suppose the stop watch shows the time of passage of an object on the ground between the fixed cross wire and the movable cross wire to be twelve seconds. Referring to the conversion table, it shows that this corresponds to a speed of one hundred and twenty miles an hour. If the conversion table is not at hand you can use simple arithmetic. The distance seen on the ground between the two cross wires was four-tenths of a mile and the elapsed time was twelve seconds. This is at the rate

of one mile in thirty seconds, two miles per minute or one hundred and twenty miles per hour.

Fig. 123 illustrates the Pioneer speed timer which is a special stop watch graduated to read directly in miles per hour. Both the speed timer and the drift indicator are furnished calibrated for nautical miles or kilometers as desired.

Fig. 123.—Pioneer speed timer.

Radio Beacon.—Another help to aviation has been invented—the radio beacon. Its use so far has been especially helpful on very long trips such as transoceanic flights. Commercial air transport companies are also using it for shorter flights.

The system consists of a radio broadcasting station equipped to send out two different signals from loop antennas, the signals paralleling each other and overlapping. The use of a loop antenna allows the signal waves to be controlled as to direction. The Morse telegraphic system of dots and dashes is used in the signals. In order to use the radio beacon the airplane must be equipped with a receiving apparatus. The operation of the system is illustrated in Fig. 124.

The broadcasting station sends out on one loop the Morse letter "N" (–·) and on the other loop the Morse letter "A" (·–). When these two signals are overlapped they form a prolonged dash (—) which is the signal for the Morse letter "T." The exact way in which they are sent out is to send first the dot of the letter "A," then sandwich in the dash of the letter "N," then the dash of the letter "A" and finally the dot of the letter "N." All the navigator has to do is to tune in the beacon broadcasting station and keep the plane headed so that the letter "T" is received at certain inter-

Fig. 124.—Principle of the radio beacon.

vals. If the plane gets off the course to one side, the letter "A" will commence coming in stronger, and if it gets off the course in the opposite direction the letter "N" will come in stronger. In this way the navigator knows in what direction he is off the course and turns back until the letter "T" again comes in strong.

Charts.—A map is a drawing, more or less accurate, of identifying landmarks. But a map that is accurate in detail, showing the exact location and position of landmarks in relation to the longitude and latitude of the earth's surface, is called a chart. The chart is always used by navigators, never a map.

There are two kinds of charts; great circle charts and Mercator's charts. The latter is drawn by assuming that the earth is the shape of a cylinder, not a ball, and then flattened out. In the Mercator chart the meridians are opened out to become straight parallel lines instead of coming together as they near the poles. Therefore, everything that is in the high latitudes is stretched out in width. In order to keep the geographical relation of the different localities, the length is also stretched out in proportion. Everything located in the latitudes near the poles is on too large a scale as compared with localities in the latitudes nearest the equator, but the course and distances measured on such charts are correct. The advantage of this type of chart is that it allows a course to be laid out in a straight line instead of in a curve, as is necessary on a great circle chart. The Mercator chart is used almost exclusively for all localities except at the extreme north and south pole regions, because there, of course, the meridians actually come together and on the Mercator chart they do not.

On great circle charts the meridians are drawn just as they occur and the scale of the locality is retained, one inch of measurement represents just as many land miles at the tenth parallel as it does at the equator.

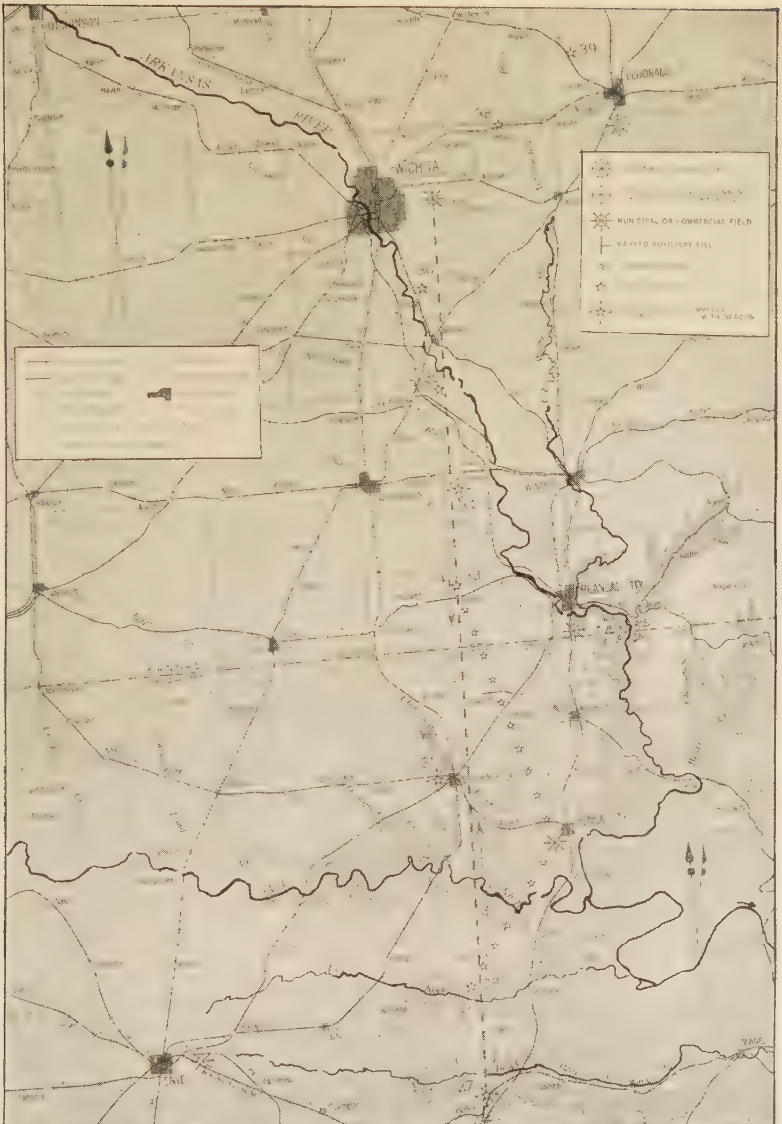


Fig. 125.—Airway chart.

On airway charts covering small areas there are compass directions printed with "north" toward the top of the sheet. The compass directions so noted also show the variation known to exist at this point and to be allowed for. Fig. 125 is a print of an airway chart compiled and published by the Aëronautic Branch of the U. S. Dept. of Commerce, and used extensively by air mail and other commercial air operators. These charts are printed in strip form as shown and cover territory adjoining established airways. Established airports are indicated by symbols signifying the facilities available and whether private or government owned. Locations of the different types of beacons are marked with a symbol denoting the kind. Highways, railroads, cities and villages are also indicated. The scale is 10 miles to the inch on full-sized charts.

The particular chart shown in Fig. 125 is of the airway route between Perry, Oklahoma, and Wichita, Kansas, the dotted line is a line of flight along the course. In the upper left hand corner you will notice a pair of arrows. The one with the full head points geographically north, the one pointing slightly to the right and with the half-head indicates the magnetic north and the amount of variation noted on it. In this locality the variation is about ten degrees easterly.

Another important thing that aërial charts show is the elevation or height of the land underneath. This is given in feet above sea level, the sea being used as a datum or base from which to measure land height. The elevation is indicated by the shaded portion of the chart. These outlines are marked with a number such as "1,000," "800," "1,400," etc. This means that all ground on the line so marked is the indicated number of feet above sea level. These lines are called contour lines, and their appearance is shown more in detail in Fig. 126. The contour lines in this illustration indicate two hills, the left being 1,100 feet above sea level and the other 1,200 feet above sea level. The level country at the base of the hills is indicated as being eight hundred feet above sea level.

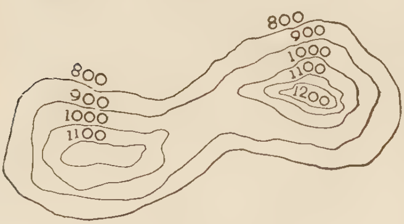


Fig. 126.—Contour lines.

Commercial Maps.—Almost any map will furnish some information of value to flying, but most ordinary maps are made to use while on the ground and therefore leave out certain information desirable to the flyer. For this reason the ordinary highway or automobile maps are not as good for flying as are maps prepared especially for the purpose. The general maps most commonly available are commercial maps, road maps of different kinds, post-route maps and geodetic survey maps.

The Rand-McNally state maps are the best of the commercial maps for cross-country flying, showing quite accurately railroads, streams and towns in their correct positions. They lack the elevation marking of hills and mountains, and they do not indicate forests or wooded sections.

Ordinary road maps are published primarily for the use of autoists and show preference to roads, then railroads and streams. These maps are not of much use as flight maps because the highways are not drawn to accurate scale, being very often too large in proportion, hiding railroads and other details important to the flyer.

No airway or other type of map is perfectly reliable in relation to highways. Constant road building in this country makes it next to impossible to keep any map up-to-date in respect to them. It is the usual practice, therefore, to use some other landmarks when following a course with the ground visible.

Flight Maps.—If it is not possible to get regular airway maps of the country over which it is intended to pass, it is possible to prepare one. Two methods of doing this are used by flyers. One is to take a strip from some commercial map, mark in details not already marked on it, then mount it. The other method is to make an entirely new map. For the latter a scale of about eight miles to the inch is found to be most satisfactory. This scale allows enough room for details without making the map too large and gives a convenient unit for estimating distances. The width of the strip map should not be over five inches, thus allowing forty miles to be covered. Five inches is especially recommended when the map is to be placed in a holder. When carried loose with no holder, the width may be increased to about eight inches.

The total length of the map need not be greater than that covering the distance to be covered in one hop, or flight. If two hun-

dred miles is contemplated before landing, the map needed will be about twenty-five inches in length, using the eight miles to the inch scale.

A flight map to be of any practical use should show the following details:

Power transmission lines.

Interurban car lines.

All railroads, indicating whether single or double track.

Rivers, streams, lakes or other bodies of water.

Main paved roads.

Bridges and railroad trestles.

Cities, towns and villages.

Regular and emergency landing fields.

Any special landmarks such as large farms, towers, churches, peculiarly shaped buildings or anything else out of the ordinary.

This detail information may be obtained from different general maps and other sources. A line should be drawn between the starting point and the destination, noting the compass course at about ten-mile intervals.

Mounting of Maps.—Lack of space in the ordinary airplane cockpit, together with the high wind velocity, makes it necessary that flight maps be mounted in such a manner that they can be easily handled and read while flying and so that they will not easily be blown out of the ship. When some form of map holder is used, the map should be prepared to fit the holder. Otherwise it should be made either to roll or fold according to the preference of the user.

Some form of backing should be used, either of cloth or tough paper. Rubber cement is best to use when fastening the map to the back, because paste or glue will cause the map to stretch or wrinkle.

Special holders are manufactured that provide for rolling the strip map from one roller onto another as the country is passed over. This type holder is illustrated in Fig. 127. When it is not desirable to use a holder, the map may be folded into eight or nine inch square sections. Then as one locality is passed the map may be turned over to the next section showing the next part of the country to be passed over. Maps are best mounted for use in this

way by cutting them apart into oblongs and mounting them on cloth. A small space should be left between each section to prevent wear at the folds. Fig. 128 shows the suggested method of folding.

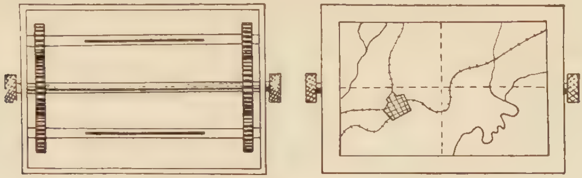


Fig. 127.—Map roller frame.

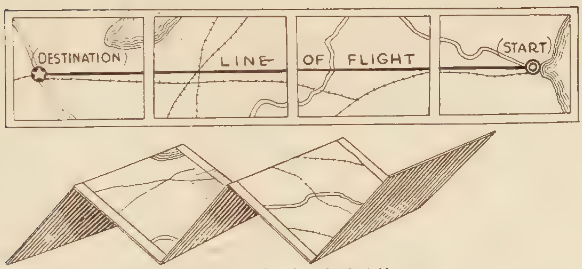


Fig. 128.—Method of folding map.

Charting a Course.—The path to be followed between the starting point and the destination is called the course. Charting a course requires only simple arithmetic and an ability to remember certain things. It is a much more simple problem to chart an aërial course than it is a water course. A boat may have to go around obstacles such as islands, rocks, reefs or land jutting out into the shortest route between two points. An airplane can, as a rule, fly in a straight line over any such obstacles between starting point and destination. There are, of course, exceptions to this; it may be necessary to go around mountainous elevations too high for the plane to climb over, or bad country where a forced landing might be disastrous, or for other reasons.

We will take Fig. 125 as our chart. Notice the variation, which is ten degrees easterly. Longitudes are also marked on the fine

lines running up and down 97°, 97° 30′, and 98°. These designate the degrees and minutes of longitude west of Greenwich.

Running across the chart from left to right, or east and west, are other fine lines. These are the parallels and are marked with the number of degrees and minutes of latitude north of the equator.

Suppose that we wanted to leave the flying field of the town of Enid, lying just east of the 98th meridian and just south of the 36° 30′ parallel, and go to the field at Arkansas City, which lies just west of the 97th meridian and just north of the 37th parallel. A line is drawn from field to field, as in Fig. 129, and is called the line of flight. Then a line, *A*, is drawn exactly paralleling the true north arrow, and through the line of flight. These two lines make an angle with each other and the angle can be ascertained by using either an angle degree scale or by taking a compass card, like that of Fig. 110, and laying it on the chart with the base line of the degree scale, or the north and south meridian of the compass card, exactly over the arrow *A* printed on the chart. If using a compass card the exact center of the card must be directly over the point where line *A* crosses the line of flight at *B*. This can be done by sticking a pin through the exact center of the compass card and the point *B*. Now the line of flight will be in the direction shown on the compass card, not allowing for errors. In this case it is northeast on the compass card or at forty-five degrees on the degree scale.

There are errors to take into consideration. First there is ten degrees easterly variation, meaning that the true course is ten degrees west of what the chart tells us, due to the fact that the compass needle is being pulled ten degrees to the right (east) of the true north. The direction "northeast" is forty-five degrees east of north (Fig. 110). Therefore, subtracting the ten-degree variation from the forty-five degree true course, it leaves thirty-five degrees east of north provided that we had no deviation error to allow. The metal parts of the plane cause an error of say five degrees easterly deviation on this heading, tending to pull the compass needles five degrees farther east than the variation does. This makes a total error of fifteen degrees that the needles are being pulled easterly from the true geographic north. Subtracting this fifteen degrees from the original forty-five degree calculated, results in having the thirty-degree mark on the compass card line up with

Fig. 129.—"Hop" chart.

the lubber line on the compass case to indicate the course to fly. This is provided the air is still or the wind blowing directly fore-and-aft or tail on. This latter is probably not the case, so the wind drift must also be allowed for.

An excellent way to understand and practice correcting all of these errors is to take a large sheet of paper and draw a circle on it, marking north, south, east and west. Then cut a smaller circle out of cardboard and mark on this all the points of the compass, using all those shown in Fig. 110. Use the smaller cardboard circle as a compass and move it around, working out different problems for yourself until you are perfectly familiar with the rules.

The government meteorological department, or weather department, will supply information on wind direction and velocity at different localities and altitudes for several hours in advance. If it is desired not to use a drift indicator, other methods may be employed to set a flying course.

One of these is to calculate the compass course necessary to fly, taking into consideration the direction and wind velocity as ascertained from the government wind reports. For purposes of calculation, assume that the wind is blowing thirty miles an hour from the northwest, at direct right angle to the course desired to fly. When the wind velocity is known the following method may be used to determine the compass course.

Referring to Fig. 130, the line of flight is from *E* (Enid) to *A* (Arkansas City). The angle of the line of flight with the true north has been determined as forty-five degrees, so the line *E–A* is drawn at a forty-five degree angle with the line *N–S*. In drawing the lines the proper length it is necessary to set a unit of measurement relative to speed and distance. In Fig. 130 this unit is one inch and equals thirty miles per hour.

So starting at *E* a line is drawn one inch long and in the direction the wind is blowing, southeast. Mark the end of this line "B" The line *E–B* represents the direction and distance which the wind moves in the unit time—thirty miles in one hour. A scribing compass is now used and, with *B* as a center and the radius *B–D* three inches, corresponding to a ninety-miles-an-hour speed of the plane, an arc is drawn intersecting *E–A* at *D*. A line is then drawn from *B* to *D*. Then another line paralleling *B–D* from *E* to *C*. Another

line is drawn paralleling E–B from C to D. Now from the figure drawn it can be seen that E–C is the proper direction in which to head the plane to overcome the drift and reach A over the most direct route. The variation and deviation must be deducted from this heading, however.

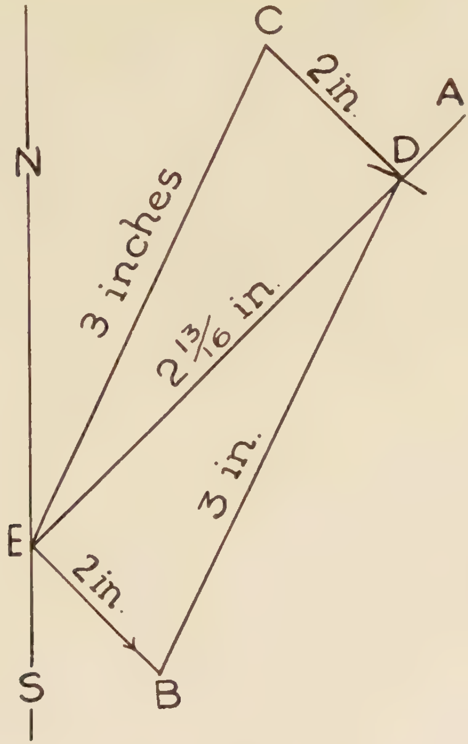


Fig. 130.—Mathematically allowing for drift.

The distance from E to D represents the ground speed. It happens to be about two and three-quarter inches in the illustration and reduced to miles and time as per the unit, figures out about eighty-three miles, taking about one hour to travel or a *ground speed* of eighty-three miles per hour. This does not mean, however,

that the plane is not traveling through the air at ninety miles an hour, but the drift has reduced the speed over the ground somewhat.

The compass course originally figured has been greatly altered after allowing for the various errors. Variation and deviation altered it fifteen degrees east. Drift altered it farther and the final compass course to be flown figures out to be seven and one-half degrees east of north.

A thirty-mile-an-hour head wind would reduce the ground speed of a ninety-mile-an-hour plane to sixty miles an hour over the ground. If wind of the same velocity were blowing from the rear it would increase the ground speed that much, resulting in one hundred and twenty miles an hour.

Charting a course may seem rather difficult to the beginner, but after a little practice in laying out courses it becomes easy and interesting. Before Colonel Lindbergh made his epochal flight across the Atlantic he had practically no technical knowledge of navigation except that which he picked up while in the Army and Air Mail service. He spent practically four weeks' time studying navigation and preparing his charts, and if enough knowledge can be gained in that short time to make such a long and difficult flight, it should not take long to pick up enough knowledge to lay out a thousand-mile course. I do not mean to convey the idea that the work can be done haphazardly or carelessly; a mistake of a couple of degrees might throw a ship several miles off its course over a distance of a few hundred miles. The rules are simple, however, and it does not require a highly trained man to navigate comparatively short flights.

CHAPTER XVI

AIRPORTS AND AIRWAYS

IF AN airport is to be commercially successful it should be as near a town or city as possible and on a well-paved and traveled highway. This is especially essential if passenger flights are to be featured. Then plenty of automobile parking space should be provided.

The privately operated airport will continue to be located in available open spaces, therefore at increasing distances from the center of towns and cities as surrounding areas become too valuable or built up. A great many things must be considered when selecting an airport site, among them adjacent highways, ease of reaching, nature of ground, possible drainage, prevailing wind and possible expansion.

In most localities it will be found that the wind blows from one direction most of the time, the prevailing wind. When the prevailing wind is invariably from one direction it is possible to use an oblong field with the wind blowing the long way. Where the wind shifts considerably it is necessary to lay out the field in an L shape, providing four directions for the movement of planes. The ideal shape is circular with runways provided in every possible direction, as illustrated in Fig. 131. The circular field requires an area not always available or requiring a considerable investment. The model airport shown has the administration and other buildings grouped in one corner at the intersection of two main highways. At the upper right hand part of the picture you can see a round white circle which is the swing platform for compensating ships' compasses. Notice that it is placed far away from any magnetic influence that might be exerted by the buildings or lighting plant.

Hangars.—The building used for airplane storage, in the manner of the automobile garage, is called a hangar and its size is that desired or essential under existing conditions. They are usually

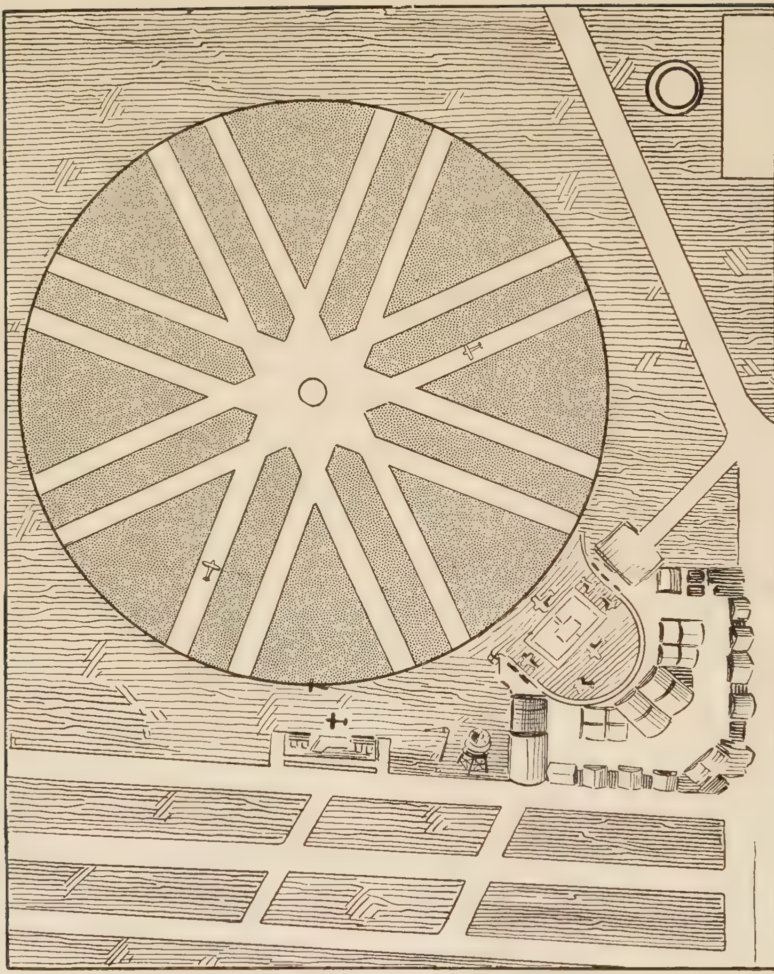


Fig. 131.—The arrangement of an ideal airport.

long, low buildings wide enough to accommodate several airplanes when placed correctly. The maximum width is governed by the structural overhead trusses possible to install, but reaches 100 feet or more at large commercial airports. The varying sizes of air-

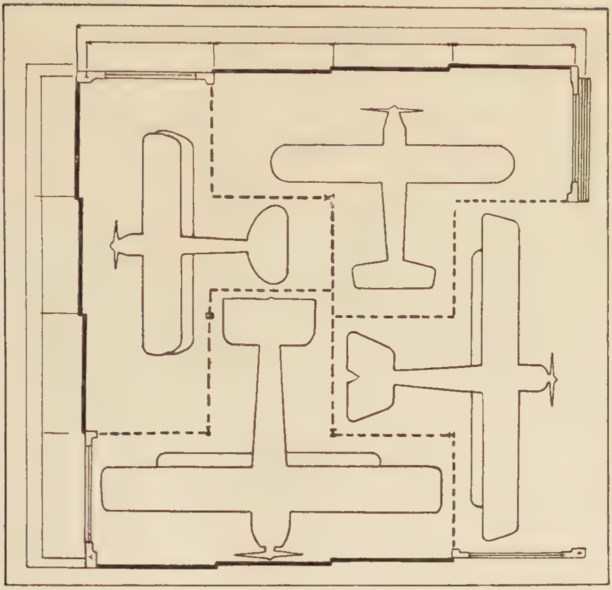


Fig. 132.—One method of placing ships in a hangar.

planes govern the number that can be stored or placed in any one hangar, but it is not unusual to accommodate eight or ten medium-sized commercial ships under one roof. They are not just run in head on or tail first, but are placed so that the tail of one ship fits in between the wing and tail of another or in other ways to use all available space. A method of storing four conventional-sized

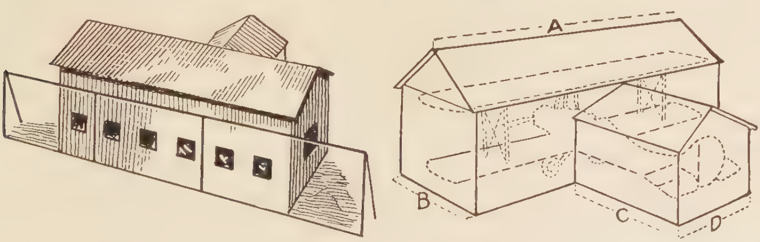


Fig. 133.—Small, single-ship hangar.

ships in one hangar is illustrated in Fig. 132. A small single-ship hangar suitable for the private owner is shown in Fig. 133.

The large doors are usually made in sections and slide open, one overlapping the other. Another method is to fold them back in the manner of an accordion or have them slide upward then horizontal and parallel with the floor. The almost universal practice is to have doors open toward the flying field, but where space permits it is better practice to have them open on the side, thus providing no opening through which dust, caused by the propeller blast of planes outside, can enter.

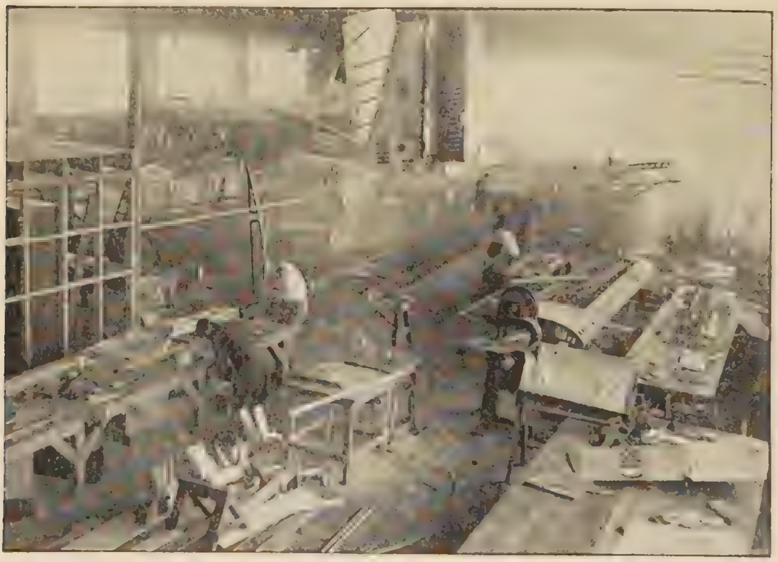


Fig. 134.—The National Air Transport wing repair department.

Fire protection should be modern and efficient because the combination of wood, fabric, gasoline and oil that goes to make up an airplane is after all rather inflammable. Large, well-organized airports provide for fueling at from forty to fifty feet away from the hangars, out of doors. Human carelessness has not as yet been eliminated, so precautions such as these are necessary.

All large buildings of an airport, whether used for storage or

shops, with the exception of administration buildings, are usually referred to as hangars. The shop hangars are large enough to provide room for the various departments under one roof. The necessary facilities required are for wing and fuselage repair, including a separate dope room, and those for engine overhaul. The doping room is probably the most dangerous from the fire hazard standpoint, dope being quite inflammable while in a liquid form.

Fig. 135.—The National Air Transport motor repair department.

Dirty or oily rags provide fuel for spontaneous combustion and should never be allowed to accumulate. Equipment should be kept clean of dope spray and dust. Smoking should be strictly prohibited and the dope room well ventilated. Mechanical equipment should be "grounded" by running a wire from every piece of machinery or other apparatus producing friction to the ground to prevent sparks from static electricity. For the same reason workers should be required to wear rubber-soled shoes on concrete floors or else provide a composition floor. The dope room and paint room should be separated from other buildings where possible. Figs. 134 and

135 show typical interiors of shop hangars with everyday activity going on.

It is not good policy for the casual visitor to walk into hangars or shops without being given permission. One rule to observe around an airport is "Hands off." Flyers dislike very much having strangers forever handling and investigating their planes. It is appalling at times to observe the ignorance with which some well-meaning, curious visitor manhandles a plane. They will flip the rudder about, raise the elevators and let them fall, heave up and down on the ailerons, thump the wings and sides of the fuselage and otherwise pursue investigations knowing well enough beforehand just what action the part performs. An airplane is not a delicate watch-like vehicle, but ignorant handling might impair the efficient operation of some vital part after the machine is in the air, resulting in an accident if not a fatality.

Visitors should not be allowed on the runways or in any area where engines are run. The larger airports provide a railing or rope barrier beyond which they are prohibited to go. Still farther out on the field a line should be provided inside of which engines must not be run. Revolving propellers are an ever-present menace and the ignorant fail to see them or consider them until too late.

The runways over which the planes travel when taking off, are usually cindered or oiled, it being next to impossible to keep grass growing when continually exposed to dragging tail skids and dropping oil. Whirling propellers create somewhat of a minature whirlwind directly underneath that sucks dust and even small pebbles up into the blades if these evils are present, hence the need of oil.

Somewhere on the field, usually on the top of a hangar, is a wind cone, Fig. 136. This is a metal ring to which is fastened white cloth in the shape of a tapering cone, the whole attached to a mounting pole. The wind blowing into the cone will tend to straighten it out, indicating the direction of the wind as well as the approximate velocity, depending upon how straight the cone is standing out. The wind cone is more often called the "sock," due to its similarity to a stocking with the foot cut out.

Very busy fields, handling a great deal of air traffic, are regulated by traffic officers who signal which runways to use, which plane has the right of way, when it is clear to take-off, etc.

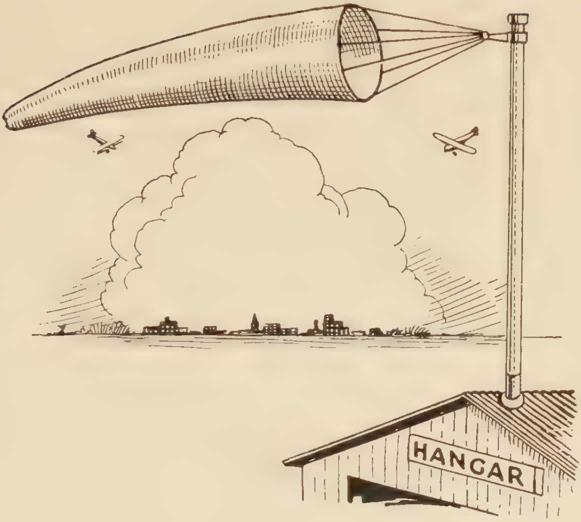


Fig. 136.—Cone used to indicate wind direction.

The life and healthy growth of commercial aviation is absolutely dependent upon adequate airport terminals. It is estimated that fully ninety per cent of all air-line activities take place upon the ground and the remaining ten per cent in the air. This is because commercial services such as aërial taxis, flying and construction schools, together with aircraft factories, require well equipped landing fields from which to operate. For this reason all modern plans having to do with municipal development include an airport location, thus including the economical advantages bound to accrue from such an establishment.

Due to the comparatively large area required and the necessary freedom from tall buildings surrounding an airport, the present locations are usually some distance from the business centers of large cities. This condition is detrimental to the best interests of commercial aviation because a great deal of valuable time is wasted in traveling to and from the landing field. This drawback is being rapidly overcome, however, through the coöperation of railroads in building landing areas over their yards when other conditions are favorable.

After an exhaustive and careful study, the Department of Commerce has established a list of requirements as to the physical characteristics necessary for a thoroughly modern and adequate airport. The Department has set up a series of ratings which identify and fix the degree of suitability of the airport as a way station or terminal. The highest of these ratings is designated as A–1–A. This symbol signifies three separate ratings, in reality, rather than one. The first A signifies that equipment and general facilities of the airport are good. The figure one signifies that the usable landing area is of sufficient size to take care of present-day needs. The second A signifies that the lighting equipment, essential for night flying, is excellent.

If the airport does not possess the qualities necessary for an A–1–A rating, it is designated by the letters B, C, D, etc., and the figures 2, 3, 4, 5, etc., depending upon the actual facilities present.

Regardless of the rating, certain basic requirements are demanded of any airport. It must, for instance, be well drained, located on firm, level ground, or else provided with wide landing strips properly surfaced. The runways must be free of any dangerous obstacle and allow safe landing and take-off. There must be no surrounding obstructions that create a hazard to take-off or landing. Its location must be on an improved road offering easy and ready access to the near-by city or town. Its markings must be such that it can be easily distinguished and identified from the air. A wind direction indicator must be in evidence at all times, including illumination of it at night. Red flags during the day and red lights during the night must mark dangerous areas. Refueling facilities must be provided as well as those essential to the comfort of pilots and passengers. It must maintain, or have within telephone reach, a staff of airport personnel.

A landing area at least 2,500 feet long in all directions is required for an A–1–A airport. If this length is impossible it may be provided with landing strips 2,500 feet long by 500 feet wide so arranged that a plane may take-off or land in any one of eight directions, each direction being not closer than forty-five degrees from that adjacent. A larger landing area is required for airports located at high altitudes due to the thin air encountered.

Other items are required of an A–1–A airport besides a large landing area. It must not be crossed by roads that are in use, its maximum slope must not be over $2\frac{1}{2}$ per cent nor a mean slope of more than 2 per cent. It must not have surrounding obstructions that would prevent a 7 to 1 gliding angle for planes landing. A building or other obstacle fifty feet high at the border of a field will require a 350-foot forward movement of a plane before touching the ground, thus shortening the available length of the landing runway by that much. High buildings already built, or being considered, must for this reason be taken into account. High poles, smokestacks, water towers, and radio towers all provide dangerous obstacles. A flyer can be counted on to see buildings, church steeples and even radio towers, but poles carry wires and a wire constitutes a practically invisible danger. It is always well to assume that wires are where poles are. It is not well to locate permanently unless the site selected is possible of expansion. Adjoining property should be available in case of need because it is most distressing mentally and financially to have a growing business and nowhere to grow.

The nature and character of the ground itself must be carefully considered. If the ground is naturally soft it will become soggy in wet weather, resulting in planes miring themselves. A smooth field with the proper slope for drainage is, of course, ideal, but very few available sites are of this nature. The usual location, more often than not, has been used for farming and is therefore rather rough. Labor, combined with drags and scrapers, will overcome this difficulty, however. Ridges or hummocks must be leveled, due to their danger while landing or taking-off. Taxiing ships over rough ground should be avoided as the continual bouncing up and down will loosen bracing and exert loads for which the ship is not intended. Uneven ground also causes water puddles during wet weather which prove detrimental to propellers and other airplane parts.

According to Department of Commerce requirements, the runways must be surfaced with either firm, solid sod, slag, crushed rock, asphalt or some other solid material to a width of at least 100 feet. The landing runways must be clearly marked, both during the day and at night, so that they are recognizable from the air.

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rating of 1 for size. In order to receive an A rating for equipment it must have one or more hangars at least 80 by 120 feet with a clearance of 22 feet. In addition to the repair equipment demanded for land airports, the seaplane airport must have a power boat available for towing, rescue work, etc. Night lighting is less definite here in order not to conflict with other navigational light requirements. In many respects they resemble the requirements for land airports. The seaplane airport must be located on, or connected directly with, a moderately calm body of water with a minimum depth of six feet and adjacent to a land highway leading directly to a near-by city or town.

The foregoing is a brief outline of the requirements necessary for an A-1-A airport. There are many good landing fields in use that fall far short of these demands but still give valuable and active service to commercial aviation. A Number 2 rating is given a field having 2,000 feet of unobstructed landing runway, a Number 3 rating to one having 1,600 feet, a Number 4 rating to one having 1,320 feet, etc. Ratings of B, C, D, etc., are given according to the equipment and night lighting arrangements which will vary with the field. All airports must, however, demonstrate their ability to handle the type aircraft they are designed to serve in a satisfactory manner before departmental approval and a rating will be given.

On the other hand, there are many airports whose facilities far surpass the minimum requirements of a Department of Commerce rating. The famous airport terminals of Le Bourget, near Paris, Tempelhof Field at Berlin, and Croydon, near London, have a far larger area, better equipment and night illumination. The airports of Buffalo, Cleveland, Chicago, Dearborn, Boston and several others have larger service, storage and passenger facilities, are provided with larger landing areas and runways, and generally exceed the Department of Commerce requirements.

CHAPTER XVII

HANDLING THE SHIP

THE wise and considerate pilot will not be too proud to talk with his mechanic; close coöperation between pilot and mechanic is one of the greatest safeguards to health known in aviation. Conversation with the mechanic and an appreciation of his work is good practice; he may have some little defect to draw the pilot's attention to, which he might not were he and the pilot not the best of friends and because of his natural reticence about talking to a haughty personage.

If you have been around an airport much you will have noticed that either the pilot or mechanic runs a rag over the wires and cables when preparing a ship for flight. The rag, besides cleaning the parts, will catch on any loose or broken strands, signaling the fact. A lifting on the wing tips will disclose any defect in the attachment fittings and bracing struts. An inspection of the tires should be made for defects or under-inflation. A glance at the gasoline and oil quantity gauges is insurance against having to "squeeze" the ship to reach its destination. If water cooling is used, the water in the radiator should be checked. It is much more satisfactory to inspect the ship and check these items while on the ground rather than to attempt it five thousand feet in the air.

Passengers in an open-cockpit plane should be cautioned, in case of a dual control ship, to keep clear of the rudder bar on the floor and the control stick. The stick moves around in a complete circle as the pilot tests the action of the control surfaces and its arc can be noted. Its action in the air is similar, depending upon the maneuver executed. On either side of the seat is a broad web belt with a safety catch attached to the loose ends. The two pieces are brought over the lap and the pointed half of the safety catch is slipped through the loop on the other part of the belt, then pressed

over. When it is desired to release the catch, the pointed end is pulled and it will then slip out of the loop.

The altimeter should be set at the altitude corresponding to that of the point of departure. In this way altitude above any territory may be calculated by subtracting the altitude shown on the chart from that shown on the instrument.

The Log Book.—In a pocket, usually at one side of the pilot's cockpit, is a log book in which a detailed record of matters pertaining to the ship and engine is kept, a regular history. In it are entered the flights it has had, giving the length in miles, duration in time, point of departure and destination, the condition of the weather on that date and other details as required by regulation. One part of the log is devoted to the motor record and contains items of repair, extent and reason, and fuel consumption for the different flights. The airplane log book corresponds to the log book of a boat. Before taking-off, items pertaining to the proposed trip are entered in the log book noting the date, time of take-off, proposed destination, course to be flown, the names of occupants and other pertinent details pertaining to the trip.

Starting the Engine.—There are traffic rules around an airport as well as anywhere else and they should be strictly observed. Planes ready to take off are taxied or wheeled to what is designated as a starting line. The engine should not be started while the tail of the ship is pointing toward an open hangar or a crowd of spectators, the resulting dust is detrimental to both person and planes. It should be pointed toward the open field or parallel with the hangars. A pilot who starts his engine with the ship in the former position is called a dusting pilot and soon loses favor with the others. This is a rule of courtesy, but there are others that should be observed in order to prevent accident.

Before the engine is started the brakes are set, or chocks placed in front of the wheels if the ship is not equipped with brakes.

When a plane has not flown for any length of time the gasoline is shut off. so, before starting the engine, it must again be turned on at the valve. It will take a moment or two to reach the carburetor and fill the float chamber. If the ship is equipped with a starter it is operated to start the engine. If not, one of the ground crew must swing the propeller, accomplishing the same result as

cranking an automobile engine. When a person swings the "prop" to start the engine, great care must be exercised to prevent injury and for this reason a set of signals is universally used.

The mechanic steps to the propeller and calls, "Switch off—gas on." The pilot repeats this, word for word, and anything else the man swinging the propeller says to him to show that each understands exactly what is wanted. If a mistake is made in carrying out the requests of the man in front, a serious accident might happen. The pilot, therefore, first makes sure that the ignition switch is off and the gasoline is turned on and the throttle part way open, just enough to provide a priming mixture for the engine. Then he repeats, "Switch off—gas on," and the mechanic will swing the propeller over several times in the direction of rotation it naturally revolves to draw a charge of gas into the cylinders. If the engine is equipped with an altitude carburetor control it should be placed in the full rich position while priming the cylinders.

After the propeller has been swung around enough to prime the engine, the mechanic will call, "Switch on—gas off." The pilot will then turn the ignition switch on and close the throttle until, as ascertained through experience, the engine will keep running when it starts. Before this is done by the pilot, possibly before the mechanic started to swing the propeller, he will pull the control stick far back, which raises the elevators and tends to keep the tail on the ground as the propeller blast hits it. If this were not done the strong blast from the "prop" might raise the tail enough to nose the ship over.

This is the critical moment for the man swinging the propeller and he must exercise caution. If the engine runs anti-clockwise, looking at the propeller end, he will grasp the trailing edge of the stick, well out toward the tip, with his left hand and bringing the weight of his body into play, will pull the propeller over one or two compression points of the engine. If the motor is of too high compression to permit it being turned over by one hand, the propeller is placed in a horizontal position, before the signal for switch on is given, and it is then necessary to place both hands on the trailing edge and use all the strength possible in pulling the propeller down and to the right.

It may be that the engine will start with one swing, but if not

one or two more attempts are made. If the engine still fails to start it is best to investigate. The gasoline flow should be checked by flooding the carburetor, the ignition wires checked for loose terminals, broken or grounded wires. If these items check O. K. perhaps the engine was not primed enough and the operation of "Switch off—gas on" is repeated.

When a booster magneto is used the engine is primed in the usual way and the engine is left with one cylinder on top dead center, or just past. Then, when the signal "Switch on" is given, the pilot turns on the ignition switch, closes the throttle and vigorously cranks the booster magneto, sending a stream of high-tension sparks through the regular magneto distributor to the cylinder ready to fire. When the first cylinder fires and the engine starts, the regular magneto takes up the ignition work and carries on.

A term that has survived the years since World War time is "contact." This is a French word corresponding to our "switch on." Another is the French word "coupe" meaning "cut." These words will be found in use at a great many airports especially in the Air Mail service. So don't be surprised if you hear the man swinging the prop call "contact" and "coupe," he is not trying to be funny but is probably a war-time mechanic.

Before starting the engine, especially if it is to be started by hand, the ship should be moved to a point on the field that insures dry footing for the mechanic. If the ground is wet or slippery, accidents are liable to result.

Warming Engine Up.—Due to the high rate of speed that the airplane engine is called upon to maintain while pulling the ship through the air, and the fact that metal expands when heated, it is essential that the engine be warmed up gradually and thoroughly before calling on it for maximum effort. A cold motor will not operate efficiently, and at times not at all; metal parts are liable to damage if heated and expanded too quickly, so after starting the engine, it is universal practice to allow it to run slowly, at about eight hundred revolutions per minute (r.p.m.), checked by the tachometer, until the water thermometer indicates 100 degrees Fahrenheit on water-cooled engines, or the same for oil-out temperature in air-cooled engines. Running with the spark control lever slightly retarded will hasten the warming up, as will closing radiator shut-

ters if they are part of the equipment. To attempt a take-off with a cold motor is to invite disaster through a back-fire and resultant fire, or complete engine failure. Warming the engine insures the lubricating oil becoming warm and thin so that it will flow freely to all bearings, very essential to uninterrupted engine service.

While the engine is warming up the operation of the engine instruments should be checked. The oil pressure gauge should register the correct pressure, the thermometers should rise gradually, showing normal operation of the pumps. Other things to check at this time are the even firing of the cylinders and the ignition system by running the engine on one magneto at a time and checking the operation for correctness.

When the oil and water temperatures have risen to the proper point, the throttle should be opened gradually, never jammed all the way open quickly, and the engine allowed to speed up, or "rev" up. Watch the tachometer to see that it will attain its correct maximum number of revolutions, known beforehand. Different type engines and propellers vary in this but most of them should "rev" up between 1,500 and 1,800 r.p.m. This insures the maximum power being available when called for. The maximum "revs" will be slightly less while on the ground than are attainable in the air, due to the inability of the propeller to pull the ship forward.

A radial air-cooled engine should not be subjected to prolonged running while on the ground. This type warms up very quickly and does not receive proper cooling under these conditions, resulting in possibly warping the valves.

The proper operating oil temperature for Wright Whirlwinds is about 100° F. and the pressure between fifty and seventy pounds. If the oil pressure drops below thirty-five pounds there is something wrong and, if in the air, the ship should be immediately landed and repairs made. The same holds true if the oil out temperature rises above 180° F.

When everything is operating properly, the motor is slowed down and the chocks removed if used. Then applying the wheel brake on the side toward which it is desired to turn to reach the starting line, the throttle is opened until the ship starts to move. If the ship were not equipped with brakes, one wing would be held

back by the ground crew, swinging the ship in the desired direction. Turning the rudder in the desired direction will assist in turning also. When the plane starts to move, the throttle is closed slightly because more power is needed to get the plane under way than is necessary to keep the ship rolling once it starts. There is no advantage in fast taxiing, rather many disadvantages. Undue jars and shocks are transmitted to the ship besides dusting spectators. It is better to taxi slowly and save both the ship and the unkind remarks of the looker-on.

Taking-Off.—A plane landing has the right of way over any on the field or about to take-off, and therefore it is essential that, before taxiing out onto the runway, the sky should be scanned for possible landers. If one is about to come in, or is circling waiting for an opening, other ships should come to a complete stop and wait until the other has landed and taxied off the field. Another safety rule is always to try the controls before taking to the air by moving the stick or wheel and rudder bar back and forth at the same time watching the responding action of the control surfaces concerned. For take-off or landing the ship should be pointed directly into the wind, toward the direction from which the wind is coming. Always be sure that there is enough room in front to allow the plane plenty of run on the ground and then enough more so that a quick, steep climb is not necessary in order to clear any obstacle. All of the room possible should be taken advantage of. Too many pilots leave themselves just enough room, and no more, to get into the air before it is necessary to "zoom" and clear some building or wires. Very often the engine elects to quit at this very embarrassing time, since it is most likely for an engine to stop while it is still comparatively cool and otherwise not functioning at its best. After a plane has been in the air for a short time the dangerous time has passed and anything that was going to happen has happened.

Taxiing on the ground should be done carefully. A tractor machine is more or less blind frontward because the engine is tilted up into the air, and objects directly in front are hidden from the view of the pilot. It is well to make a mental note of any and all obstructions on the field and plan on giving them a wide berth. Taxiing at a speed faster than one at which a very quick stop can

be made is dangerous, notwithstanding the application of wheel brakes. The safest way while taxiing on the ground when another machine is about to take-off or land is to wait. The other fellow then knows that you are going to stay there and can figure on missing you. If you should continue to move he doesn't know when you might turn or how fast you might speed up and change your position. Always play safe.

For the take-off the throttle should be opened gradually, not throwing a sudden load and shock on the motor, the propeller, the pistons and all working parts. Rather they should be given time to pick up speed naturally. At the same time that the throttle is opened the control stick is pushed forward as far as it will go, lowering the elevators and raising the tail, which puts the ship in a flying position. This reduces the angle of attack, and consequently the drag, allowing the plane to pick up speed in the least possible time.

There is a trick in knowing just how far to raise the tail in order to place the plane in its flying position. Of course, one way is to watch the spirit level indicator, but this is rather bad practice when taking-off, because the eyes of the pilot should be watching ahead. As the ship gains speed, less effort will be needed on the stick to hold the tail up; the increasing wind will permit leveling the elevators more and more by bringing the stick back toward neutral. The different positions of a ship while taking-off are illustrated in Fig. 137.

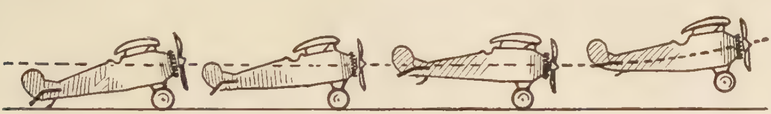

Fig. 137.—Positions of ship during take-off.

Before attempting to fly a strange ship it is best to have the tail raised until the ship is in its flying position. Then make a mental note of some point forward that lines up with the horizon. The horizon is always a more or less fixed datum point. In the old Curtiss training planes, using the Curtiss O X 5 motor, we used to line the valve rocker arms on the horizon and then knew that

the ship was flying level fore-and-aft. All ships have some point on them that can be used in this manner.

While running over the ground for a take-off there will be a rumbling sound through the ship and an occasional sharp bump. This noise is caused by the wheels striking uneven places on the runway.

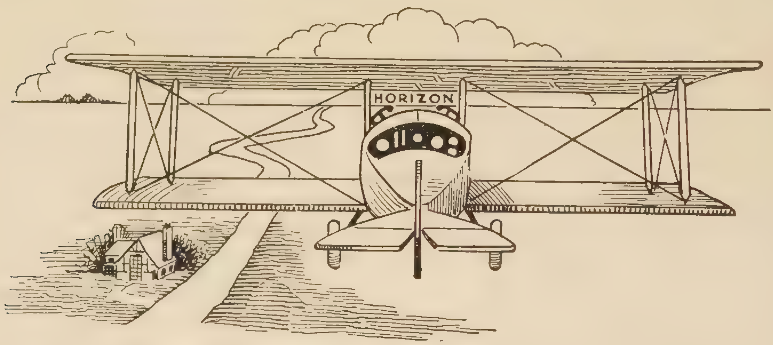

Fig. 138.—Lining up a datum point with the horizon to check flying position.

When the ship has attained flying speed, which can soon be recognized, it will leave the ground of its own accord if the controls are held in neutral, but very few flyers wait for it to do this. They prefer to "pull it off" by pulling back on the stick. The instant of leaving the ground is not noticeable to the passenger on his first hop, due to the wheels' continuing to revolve for a time, even after leaving, and the rumble continues. The pilot knows, however, because the ship becomes very limber, necessitating greater operation of the controls to keep it level.

During the take-off the controls must be operated in order to keep the ship headed straight, to keep it from tipping sideways and from trying to veer off to the side. As the speed increases, the controls become more and more touchy, responding quicker to the movement of the stick and rudder bar. At first they are very loggy, necessitating quite a movement in order to get any response from the ship.

When the ship leaves the ground it is best and safest to continue straight ahead, climbing at a normal rate until a safe altitude has

been reached before attempting a turn. If too great a climbing angle is attempted the tone of the motor will change and sound as though it were laboring. Leveling out again will relieve the engine and increase the flying speed to a safer point.

Rules of the Air.—The traffic rules of the air are very similar to those applying to automobiles, with the exception that the slower craft has the right of way when being overtaken or passed. The machine passing must avoid the one being passed and pass at least three hundred feet away, whether meeting head on or overtaking. A machine approaching on the right has the right of way, but don't try to take the right of way at any time. It is much wiser and safer to give way. The other fellow might be a beginner or ignorant of the rules; don't try to force your right of way down his propeller.

Another good personal rule to make for yourself is to fly at a good height on cross-country or long-distance flights. One reason for this is that the air is, as a rule, smoother high up, not being affected by cascades or uneven ground. Another reason for high flying is to give you plenty of time in which to select a landing field and have plenty of time to glide to it in case of engine failure. A plane has what is called a gliding angle which is the flattest glide possible while maintaining flying speed without the aid of the engine. Some planes when at five thousand feet altitude (nearly one mile) will glide forward twenty-five thousand feet (nearly five miles) before touching the ground. The gliding angle is then referred to as being five to one, because the ship can glide forward five times its height. Altitude shows more country in sight also, making finding the course easier if relying upon landmarks.

The wind velocity usually increases with altitude, so if the wind is following, or "on your tail," getting up into it will increase the ground speed of the plane considerably. If the wind is head on it is better to hunt another altitude level where the wind is more favorable. Rain clouds very seldom are found higher than five thousand feet, except in the case of very severe storms, and if flying at a good high altitude it is not necessary to go around such obstacles—they can be gone over. One very important cross-country rule is: do not fly until the fuel supply gets dangerously low. Many a good man has come to grief by trying to "squeeze" the gasoline tank and reach his destination. Much better to land near some

town and fuel up than have to come down with a dead stick on possible dangerous ground miles from any source of supply.

There are a great number of "don'ts" connected with aviation, but I believe that a "don't" and live is better than a "do and die." They should be taken to heart and lived up to. I have failed to heed some of them at times, resulting in grief, and in consequence I have learned my "don'ts" pretty well.

Banking.—When it is desired to change direction it is necessary to tip the ship so that the wing on the inside of the turn is lower than that on the outside of the turn. This provides an air cushion, that prevents the ship skidding. This tipping is called *banking*. The rudder must be operated at the same time, but seldom requires more than a very slight movement to complete the turning of the ship. As the ship tips up on its side the effect of gravity, or the center of gravity, changes and tends to make the ship's nose fall slightly. For this reason it may sometimes be necessary to apply the opposite rudder to that of the bank. In other words, it might be necessary to apply a very slight amount of right rudder while banking to the left. The majority of ships, however, require a slight amount of rudder in the same direction as bank.

If the ship is banked over ninety degrees, or until it is on its side, the action of the ailerons and elevators will be reversed, the rudder becoming the elevator and the elevators the rudder. This action commences quite a little before ninety degrees, so that when banking steeply on a turn, it is occasionally necessary to neutralize the rudder in order to keep the nose up and the ship from losing altitude.

If the bank is made too steep without proper manipulation of the other controls, the ship might slip sideways toward the ground, indicated by a wind striking the side of the face from the inside of the turn. If the bank is not steep enough and too much rudder is applied, the ship will skid, indicated by a wind striking the face from the outside of the turn. If the latter is continued or overdone the tail might commence revolving with the nose as a center, resulting in what is called a "tail spin." The bank and turn indicator will show whether or not the turn is being made correctly by the position of the hand and ball as explained in the chapter on instruments. This provides mechanical flying for fogs or darkness.

A pilot soon learns the feel of his ship and knows just when the bank and turn are being made correctly without the aid of such instruments.

Landing.—As altitude is increased, atmospheric pressure decreases, producing physical effects on the airplane occupants particularly noticeable in the ears. It will become increasingly difficult to hear until the ear drums "snap" and accustom themselves the change in pressure. The opposite effect is produced when descending.

Descending from any altitude greater than 2,000 feet should be done by stages, leveling off about each 1,000 feet of drop and cruising there long enough for the body to become accustomed to the increase in atmospheric pressure. This is particularly advised in case the flight has been at a considerable altitude, say eight or ten thousand feet. A quick descent from such a height might produce a distressed feeling in the ears and a dizziness which will, of course, disappear within a short time after landing, but nevertheless is not desirable. A deep-sea diver is brought up from the depths in easy stages, being halted at different levels for some time in order for the body to adjust itself to the changing pressure. The same rule holds true for the air. Commercial flying very seldom reaches an altitude of over two thousand feet, so that the descent may be made without regard to atmospheric pressure changes, although it will be noticeable to some extent.

When aproaching the landing field preparatory to coming down, it is well to make a mental note of everything in sight, buildings or other obstructions surrounding the field, the position and location of the landing circle or "T," if one is displayed and the direction of the wind as indicated by the cone. Any activity on the field should be given consideration especially as regards other planes preparing to take-off. It is a peculiar fact that a plane on the ground is usually plainly visible, but the minute it leaves, it seems lost to view and difficult to distinguish. Other ships in the air are not noticeable, and for this reason a constant watch must be kept to guard against approaching too close before being aware of them.

After having dropped down to the eight hundred or thousand foot level, it is the rule to circle the field at least once and better, twice. This allows those on the ground to become aware of your

presence and intention to land, for you to take in all the details of the field including the wind direction and exact point in which it is desired to land, together with any necessary maneuvering to avoid obstructions.

As the landing ship completes the last circle of the field still more altitude should be lost as it travels with the wind to a point about one thousand feet back of the field edge. When turning from flying with the wind to a direction into the wind more altitude will be lost because the wind is going away from the ship, eliminating somewhat the cushioning support effect. This must be taken into consideration and enough altitude maintained before making the final turn back into the wind to approach the field for the landing. This last turn should not be made with a steep bank, which is dangerous too near the ground, as there is not sufficient altitude to recover in case of trouble.

When straightened out into the wind, headed for the runway and a landing, the altitude should still be at least three hundred feet. Practice soon acquaints the pilot with the gliding ability of the plane so that he may gauge just how far back and at what height to start the "glide in" for different force of head winds. A stiff wind will, of course, slow the ship up quicker than will a light breeze. If the glide in is started too far back and into a stiff wind, it will slow the ship down to such a slow ground speed that it won't be possible to reach the field and the throttle will have to be opened to pull it in. If the start is not made far enough back and at a low enough altitude in a light breeze, the ship is liable to "overshoot" the field at a speed that carries it right past without being able to land. In this case it is necessary to open the throttle and make another circle.

In order to keep the engine warm and cleaned of too rich a mixture, a thing liable to happen while the engine idles on a long glide, the throttle is opened and closed occasionally during the descent and the radiator shutters are closed also. Then the engine is always ready to respond to the throttle in case of need.

A long, easy glide is much easier for the beginner to control than the steep glide so popular with old-timers. The steeper the glide the more speed is developed, assuming the angle of a dive. Anyway, at about fifteen feet above the ground the stick should be brought back gradually, leveling the ship out so that when about

two or three feet off the ground the ship will be gliding horizontally with it and level. With the motor idling, the gliding cannot continue for long and as the speed reduces below that necessary to produce lift, the ship will start to settle. At this instant the stick is pulled still farther back, very gradually, and increasing the angle of attack, which provides additional drag and causes the ship to settle to the ground. The perfect and ideal landing is accomplished by causing both wheels and the tail skid to touch the ground at the same instant, called a three-point landing. This is illustrated in Fig. 139. This is hardly possible to accomplish without being familiar with the ship or without a great deal of practice.

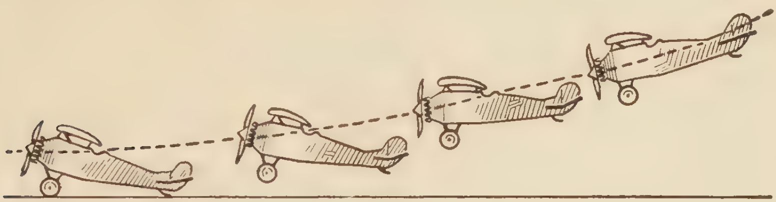

Fig. 139.—Positions of a ship during a three-point landing.

A great many pilots, when flying a strange ship, allow the wheels to touch first as in Fig. 140, then let the tail settle by its own weight as the speed lessens.

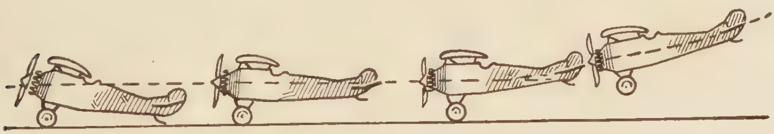

Fig. 140.—Positions of a ship during a tail-high, or wheel, landing.

As the landing gear strikes the ground the old familiar rumble will be again heard, as when taking-off, but will sound about three times as loud, because of the comparative quiet while gliding in for a landing with the motor idling. From the time the motor was throttled down until the wheels touched the ground probably no more than forty-five seconds have passed.

Shutting Down Motor.—It is just as important to allow the engine to cool gradually as it is to allow it to heat gradually, so with a

water-cooled motor, it is allowed to run slowly until the water temperature drops to normal, and with an air-cooled motor, it is better to cool it coming down and then shut it off as soon as possible after landing. Instead of shutting off the motor by the ignition switch, as is done with automobile motors, the gasoline supply is shut off and the engine is allowed to run until all the fuel is exhausted from the carburetor. Another reason for draining the carburetor in this manner is to make sure that all gas mixture is used up, thus preventing pre-ignition through possible carbon deposits in the cylinders which would cause the motor to continue running erratically, and possibly reversing its direction of rotation even after cutting the ignition switch. Removing all the gasoline mixture also prevents the cylinder walls from being washed clean of oil, leaving them well lubricated for the next start.

If it is necessary to leave the ship unguarded for any length of time or in the open overnight, it is best to stake it down to prevent possible damage from winds. Staking is best done by running a rope fastened to each outer interplane strut to a stake driven in the ground. Another rope should be passed over the fuselage back near the tail and fastened to other stakes. The propeller, engine and the cockpits should be covered.

CHAPTER XVIII

ACROBATIC STUNTS AND MANEUVERS

THE handling of an airplane in such a manner that it is made to assume acute angles in the air, other than those necessary for straight flying, results in positions and maneuvers called acrobatics, or stunts.

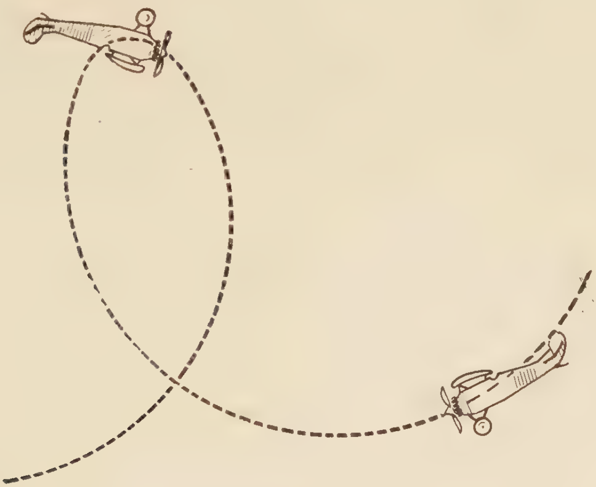

Fig. 141.—The loop.

The Loop.—The loop is, I believe, the most common and best known of all aviation stunts. It is done by every pilot handling a plane capable of it, and attempted by all whether the plane is capable of it or not. One definition of this maneuver might be, flying a plane in a circular path up and down, or vertically.

In order to loop with a plane of comparatively low power it is necessary to dive with engine on for some distance in order to at-

tain speed and momentum enough to carry it over the top of the loop. The path followed by a looping plane is illustrated in Fig. 141.

From straight and level flight, with motor wide open, the ship is nosed over slightly, but not straight down, for perhaps ten or fifteen seconds or until the wind commences to whistle through the rigging. Then, keeping the motor full on, the stick is pulled back quickly, but without jerk or snap, as far as it will go. This results in sending the plane's nose toward the sky and then over on its back, where it will seem to hang motionless for an instant and all that holds the pilot and passengers in the cockpits are the safety belts. As the ship starts to fall nose down from the upside down position, the throttle is closed and the weight of the engine will complete the straightening out, nose down. The stick is held well back during this much of the maneuver and until the nose begins to come up again out of the dive. Watching the leveling datum point on the plane's nose, the stick is pushed forward just before the datum point reaches the horizon, and as the wind whistle through the rigging dies down, the throttle is again opened gradually and the motor picks up the flying speed.

The Stall.—If insufficient speed is gained to pull the ship over the top of the loop the ship might do something like that illustrated in Fig. 142. The critical moment in a loop is when the ship should come over on its back and it is just before reaching this point that an under-powered or under-speeded ship is liable to give out, stall and start to fall off sideways as at *A*, Fig. 142. It is then best to throttle down the motor and let it continue, following the path outlined in the illustration. At *B* is a position called a side slip, or wing slip, the ship falling toward the earth with one wing tip down. The weight of the engine, if the throttle is closed, will eventually cause the nose to drop and at *C* the ship is in a nose dive. It is then necessary to pull back on the stick until the ship again assumes normal level flight, and the throttle is again opened.

Stalling is nothing to be afraid of provided it happens at sufficient altitude to allow the completion of the maneuver before reaching the ground. It is a regular maneuver and often done intentionally. If it happens unintentionally the pilot can be forewarned

by the laboring sound of the engine, the unresponsiveness of the controls and the sensation of hanging suspended in the air.

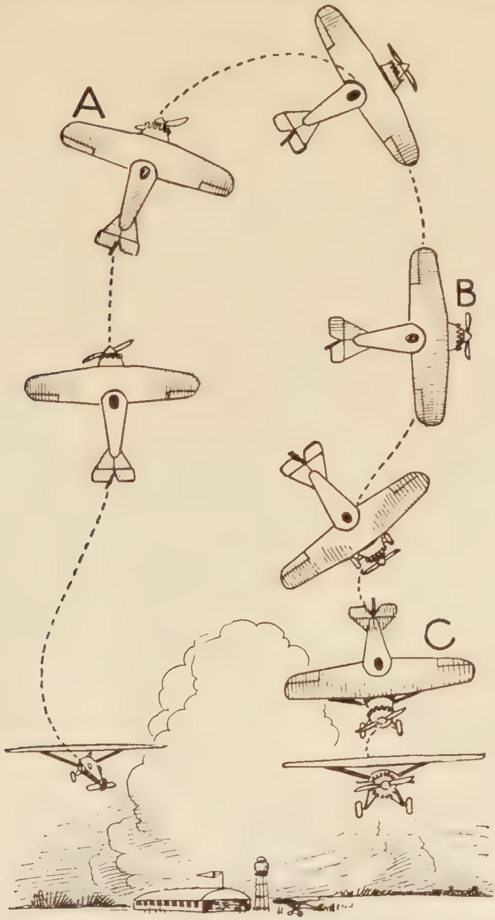

Fig. 142.—The stall, or wing-over.

The Spiral.—Another very common maneuver, hardly called an acrobatic or stunt, is the spiral in which the ship follows the path illustrated in Fig. 143, with motor off or throttled down. It amounts

to a series of horizontal loops, with the continued circling causing a loss of altitude at the same time. The maneuver is done when it is desired to come down and keep over a certain small area underneath.

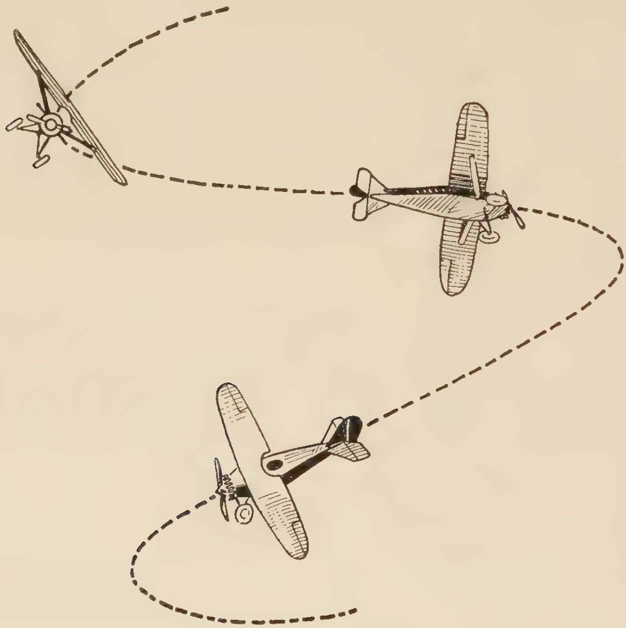

Fig. 143.—The spiral.

In order to spiral it is necessary to bank well over as for a turn, controlling the bank and turn with the ailerons and rudder but allowing the nose to drop slightly in order to lose altitude. The maneuver is called a vertical spiral when the bank is increased to such an angle that the rudder and elevators exchange functions each acting in the normal capacity of the other. Care must be taken not to allow the nose to drop too low during a spiral or it will result in a tail spin.

The Tail Spin.—The most common of the spectacular maneuvers, approaching the aspect of a "stunt," is the tail spin. This happens when the tail rotates, describing a larger arc than does the lowered

nose. As the wings rotate, with the fuselage as a center, the machine as a whole describes another arc after the manner of a cork screw, as illustrated in Fig. 144. The dotted line indicates the path of the left wing tip, the solid dash the center of the fuselage and the dash-dot-dash line the path of the right wing tip.

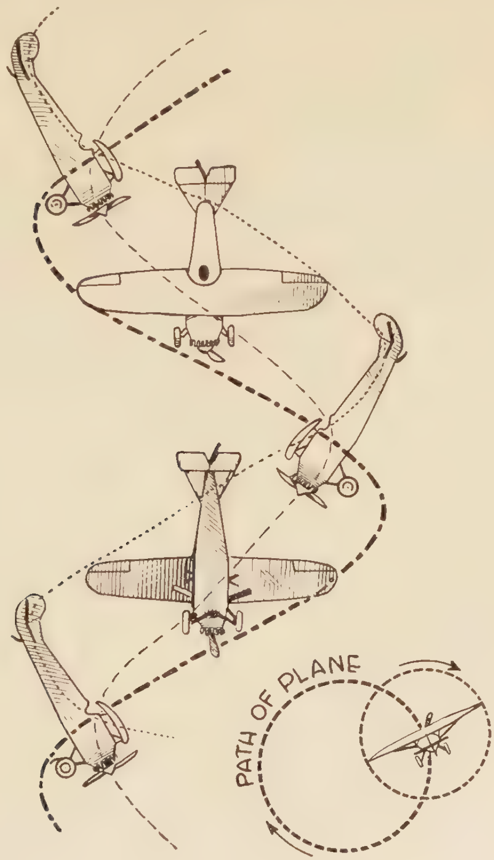

Fig. 144.—The tail-spin.

The maneuver is accomplished by closing the throttle and either allowing the ship to stall on an even keel by waiting for it to lose

necessary flying speed, or else pulling it up into a stall. At the moment that the controls become almost inoperative the rudder and aileron controls are reversed, that is; left aileron and right rudder are applied at the same time and the ship will commence to spin. The stick should be kept quite well back to keep the ship from going into a tight nose down spiral and not a spin.

Another way to go into a spin is to stall and then pull the stick back and to the right simultaneously, applying the right rudder at the same time; that is, right aileron, nose up, and right rudder. This results in an acute skid and the tail spins around the nose. This latter is really a tight spiral but can be relieved by reducing the amount of aileron and rudder.

A spin may be controlled as to tightness and speed depending upon how far the controls are moved.

In order to come out of a spin, or any other acrobatic maneuver, whether accidental or intentional, all controls are placed in the neutral position that they are in for normal straight and level flight. This will always result in making the nose drop and the plane pick up speed in a nose dive. Then the stick is pulled back until normal flight is regained and the throttle opened.

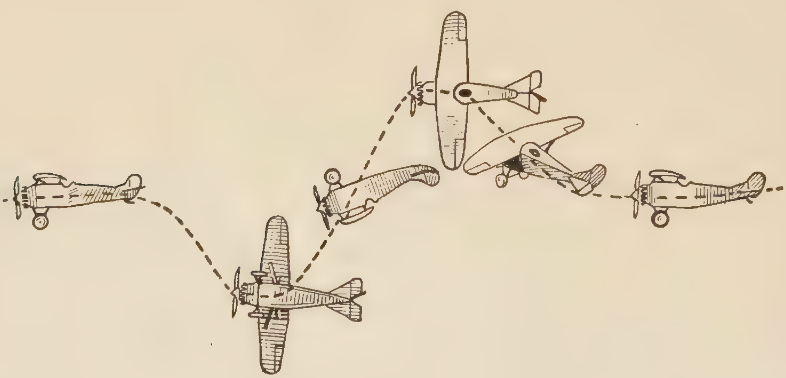

Fig. 145.—The barrel roll.

The Barrel Roll.—Getting into the more complicated acrobatics, we come to the barrel roll, illustrated in Fig. 145. This might be defined as a tail spin done horizontally to the ground instead of

vertically. It can be accomplished only by very high-powered ships with throttle wide open.

To execute a left barrel roll, the stick is pushed all the way left for left aileron, and slightly back as full left rudder is also applied. This will result in the ship turning wing over wing, the nose being guided by the movement of the elevators to keep the nose from falling. Until one is used to the maneuver and how to execute it with different type ships, the result might be almost anything from a forced landing to an upside down spiral. Practice will also reduce the slight dizziness sometimes experienced, which makes it difficult to know when the ship is right side up in order to come out of it. I have known beginners to fly for quite a time absolutely upside down and upon landing swear that they thought they were on an even keel.

To bring the ship out of barrel roll into level flight, the controls should be placed in neutral while in about a vertical position to give the control surfaces sufficient time to act and straighten the ship out by the time a level keel is gained.

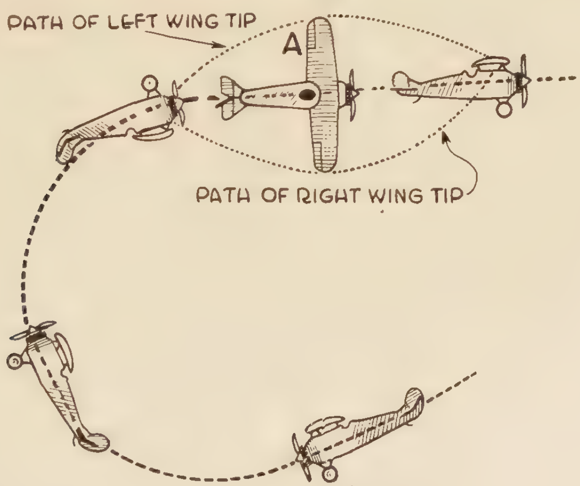

Fig. 146.—The Immelman turn.

The Immelman Turn.—A maneuver used a great deal during the World War to effect a quick reversal of directon is called the

Immelman turn, named after the German flyer who conceived it.

The maneuver is started as is the loop, but as the plane climbs, one wing is caused to droop slightly through manipulation of the ailerons, so that, at the top of the loop, the wings are vertical to the ground. Continuing the control movement causes the ship to gain an even keel, right side up, as illustrated in Fig. 146. The throttle is kept open at all times during this maneuver.

Another way to accomplish a quick reversal of direction is to complete one-half of a barrel roll or until the ship is on its back, then the throttle is closed and the stick pulled all the way back. When the ship has completed one-half of a barrel it is in the same position as when at the top of a loop and level flight is regained in the same manner as when coming out of a loop.

The Vertical Bank.—When the wings stand vertical to the ground, as at *A* in Fig. 146, the ship is in what is termed a vertical bank, provided the stick is pulled back to cause the ship to describe an arc. As said before, the action of the rudder and elevators is just reversed while the ship is in a vertical bank, so the rudder would have to be moved to keep the nose level with the horizon and the elevators pulled up, or the stick back, to cause the nose to come around in a turn.

The Wing Slip.—In order to execute a wing slip the ship is placed in the same position as though for a vertical bank but with throttle closed at least part way, keeping just enough headway to actuate the controls. The stick is kept in neutral or even slightly toward the front of the ship to prevent the ship coming around in a turn or spiral. The rudder is manipulated to prevent the nose from falling. With the controls in this position the ship will slide sideways toward the ground and at the same time move forward depending upon the amount of throttle. This maneuver is executed in order to lose altitude quickly and provide somewhat of a thrill.

In order to come out of a side slip the throttle is closed and, if sliding with left wing down, the left rudder is applied, causing the nose to fall into a dive after which the stick is pulled back, bringing the ship up to level flight again when the throttle is opened.

The Outside Loop.—Another maneuver, carried out as an experiment by the United States Navy Air Service to procure data in building fighting planes, is the outside loop. This is a maneuver that

I strongly advise against trying. It places a terrific strain on every part in the ship and only one built especially for it could possibly hold together. The maneuver is illustrated in Fig. 147, as done by Lieutenant Alford A. Williams, Jr., in a Curtiss "*Hawk*" plane powered with a Pratt & Whitney "*Wasp*" engine during February, 1928.

Fig. 147.—The inside-outside loop.

Starting from a normal level flying position, with throttle closed, the stick was pushed gradually forward to the instrument board, resulting in a dive. The stick was held in this position and as the ship started upward again with the pilot on the outside of the loop, the throttle was opened wide and the ship climbed up to normal flying position again.

Then a half barrel was executed which again turned the ship over on its back, and with the throttle still wide open, the stick was again pushed forward. The result was another dive and climb to the top where the throttle was closed and the controls held so that the ship again dived until upside down the third time. At this point another half barrel was accomplished and normal level flight regained. Lots of fun for Lieutenant Williams—but don't try it yourself!

CHAPTER XIX

PARACHUTES

THE parachute has reached a place in aviation such as is held by life-saving devices on boats. It is really the life-saver of the air, enabling passengers and pilot to leave a disabled airplane in mid-air and land safely. As will be explained later, it is possible to guide the parachute's direction somewhat while descending.

There are several makes of parachutes, the Irvin having adopted the name "air chute" instead of parachute.

The need for such a device was first seriously felt during the latter part of the World War and was considered important enough by the United States Air Service that they appointed a Board of Aëronautical Engineers to investigate all existing types of parachutes. The chief points they considered as essential were:

1. It must be possible for the aviator to leave the aircraft regardless of the position it might be in when disabled.

2. The operating means must not depend on the aviator falling from the aircraft.

3. The parachute equipment must be fastened to the body of the aviator at all times while in the aircraft.

4. The operating means must not be complicated or liable to foul and must not be susceptible to damage through ordinary service conditions.

5. The parachute must be of such size and so disposed as to give maximum comfort to the wearer and permit him to leave the aircraft with the least difficulty or delay.

6. The parachute must open promptly and must be capable of withstanding the shock incurred by a two hundred pound load falling at a speed of 400 miles an hour.

7. The parachute must be steerable to a reasonable degree.

8. The harness must be comfortable and very strong and designed so as to transfer the shock of opening in such a manner as to pre-

vent physical injury to the aviator. It must also be sufficiently adjustable to fit the largest and smallest person.

9. The harness must be so designed as to prevent the aviator from falling out when the parachute opens, regardless of his position in the air, and at the same time it must be possible to quickly remove the harness when landing in the water or in a high wind.

10. The strength "follow through" must be uniform from the harness to the top of the parachute—bearing in mind the old axiom —"No chain is stronger than its weakest link."

11. The parachute must be so designed as to be repacked easily with little time and labor.

As a result of tests the Irvin air chute type was found to contain all these important features and has been used as standard equipment for the United States Air Service.

The parachute has been the means of saving many lives in emergencies covering practically every form of accident, such as wing collapse, collision, control failure (even at such a low altitude as one hundred and fifty feet), engine failure during a night flight with no possible landing place, being catapaulted from aircraft while flying at high speeds, spins, nose dives, etc.

The Irvin air chute is of the "free type, manually operated" parachute. It is termed a "free type" parachute because it is carried complete in one unit, strapped to the person of the aviator. It has no attachments whatever to the aircraft and operates entirely independently of it.

In emergency it is only necessary to jump or drop from the aircraft at any point that is most convenient and the easiest. No avenue of escape is cut off as is the case where parachutes are attached to some part of the aircraft, or where their means of operation depend on some mechanical attachment to the aircraft.

It is termed a "manually operated" parachute because the aviator operates the air chute at will by a slight pull on the "pull ring" which is located in a readily accessible place on the harness. With this method of operation the aviator can open his air chute immediately after he leaves the aircraft, or if he desires, he can make a long, "free drop" away from burning wreckage or an enemy plane before opening his parachute, the design and construction of the harness preventing any bodily injury from the opening shock.

Irvin air chutes are made in three different sizes: twenty-four feet in diameter for general service use; twenty-eight feet in diameter for exhibition and training jumps; and twenty-two feet in diameter to be used in conjunction with the twenty-eight foot air chute on exhibition and training jumps.

The general service chute is standard because of its moderate rate of descent and its small and compact size. It is packed in three different types of containers; the "seat" pack, the "lap" pack, and the "back" pack. The seat pack is used as a seat cushion, thus removing all weight and bulk from the person of the aviator and is the type in most general use by pilots.

The lap pack has been developed for the use of machine gunners and photographers, or anywhere it is not desirable to use a seat pack.

The back pack has been designed for use in balloons, airships and other types of lighter-than-air machines. This type, as its name implies, is carried on the back and permits complete freedom of movement for walking or climbing about in the rigging of an airship.

The weight of the twenty-four foot air chute complete with harness and any type of container mentioned is approximately eighteen pounds. The average rate of descent is sixteen feet per second. The larger the diameter the slower the descent, while the combination of the twenty-two footer with the twenty-eight footer permits a very slow and lazy descent, especially adaptable to training where it is desired to instill confidence in the beginner.

The air chute is secured to the aviator by a specially woven linen webbing harness. This webbing has a tensile strength of 3,000 pounds and is reënforced on all metal parts. The harness is adjustable so as to fit persons varying widely in size. It is also designed to support the person so that no bodily injury can occur when opened suddenly.

The metal parts are the snaps and adapter buckles used in securing the harness and adjusting it to the size of the aviator. They are made of chrome nickle steel and have a tensile strength of over 5,000 pounds.

The fabric used in the air chute body is of a specially woven high-grade silk.

The lines connecting the parachute body to the harness are called suspension or shroud lines and are made up of silk cords. These cords are continuous from their point of attachment on one side of the harness to the other, passing through and over the top of the air chute. There are no knots or splices anywhere in their length. It is necessary that a vent be provided and this is made in the apex, or highest center point of the air chute. If no air were allowed to escape through the vent a solid cushion would result and the chute would be very unstable, swinging from side to side and also descending very rapidly.

A small miniature parachute, called the "pilot chute," is attached at the peak or apex of the main chute by means of a separate silk cord. This pilot chute is thirty inches in diameter and is constructed with steel ribs, similar to an umbrella, and a spring in such a manner that it folds up under tension and thus folded is packed in the container. When the container is opened the pilot chute springs out, catches the air and leads the main chute out into the line of flight. This results in a very quick and positive opening of the complete apparatus.

The container or pack into which the air chute is packed is fitted with pockets in which to stow the shroud lines and keep them separated from the air chute. It is also provided with flaps to keep the pilot chute separated from the main chute.

The flaps are held closed through the use of small metal pins passing through eyelets. Attached to the pins is a cord of flexible aircraft cable terminating in a metal ring placed in a small pocket handy to the aviator's reach. The ring and cord constitute what is called the "rip cord." The operation of the air chute is accomplished by a jerk on the ring which removes the locking pins from the eyelets of the container, allowing the air chute to free itself into the air immediately. The average time required for the air chute to open completely and assume normal descent is approximately one and three-fifths seconds after the rip cord has been pulled.

The life of an air chute depends upon the care taken of it. It should be taken out of its container, if not used before, at least every two months, allowed to air thoroughly, inspected for any de-

fects forming and then carefully repacked. Parachutes eight years old are still in service after this kind of care.

Damage may be caused to the parachute by dampness, oil or storage battery acid. The latter is very subtle in its action on the fabric, at times its presence not being apparent to the eye although slowly and surely eating away the strength of the chute. If the air chute is placed in contact with a battery it should be immediately cleaned of the acid spots and dried.

If the parachute becomes wet or oil soaked, it should be immediately taken from its pack and steam dry cleaned. The chute should be hung up by the entire group of cords upside down. It should never be dried in the sun, always in the shade. Do not wring the chute out after cleaning, squeeze it, then hang up to drain and dry.

Whenever deterioration of the parachute material is suspected, and at least once every six months otherwise, it is recommended that the parachute be dropped from a plane, with a two hundred-pound weight attached, from a height of one thousand feet. An inspection after such a test drop will disclose any needed repairs.

While it is difficult to give practical instruction in parachute jumping in a book, several basic rules might well be placed firmly in the mind. Before leaving the ground, make sure that the leg strap snaps and breast strap snap are fastened. Also make sure that the rip cord ring is in the pocket of the harness and handy to the reach. Always shut off the ignition switch before leaving the ship.

Diving from an aircraft in the position assumed when diving into water is bad practice. The jumper's head will be down or he is very liable to turn over and over in the air while falling before the chute opens, very likely being in an awkward position when the harness pulls him upright. If falling with head down when the chute opens quite a jerk will be experienced. Experience has shown that leaping from the aircraft in a sitting position as though to land in a net is the proper way. In this position the body and head are kept more or less upright, the parachute trails out behind and above, then when it opens no jerk or inconvenience is felt.

The instinct of the novice is to pull the rip cord ring at once, occasionally even before completely leaving the ship. This is bad practice. It is better to make sure that the ship's tail surfaces have

been cleared, by counting up to five, before pulling the rip cord to insure against becoming fouled by the rapidly approaching empennage. In the case of a crippled ship or one on fire, it is the rule to fall as far away as possible, making what is called a "free drop," keeping an eye on the ship to make sure that it is not falling on top of the jumper. There have been cases of a pilotless plane having spiraled, spun or wing slipped toward the aviator seemingly intent on destroying him along with itself. In this event it is well to keep your wits about you, because it is absolutely necessary that the parachute be not opened until a safe ditsance away. This is much easier said than done. Until a person has made several jumps, everything inside seems to come right up, the senses seem to be slipping and the jumper about to "pass out." After two or three jumps, however, these nauseating sensations pass and the jumper can begin to enjoy the sense of falling, being confident that his rapid descent will be checked within a second or two after the rip cord is pulled.

Although only a steady pull of ten pounds is necessary to release the rip cord, the better and positive way of opening the chute is to pull the ring with a vigorous jerk. The jerk makes sure of positive and quick operation regardless of conditions or the position in which the falling aviator may find himself.

The parachute may be guided as to direction by reaching up and pulling down the shrouds on the side toward which it is desired to go. This action tips the envelope so that the supporting air escapes from the one side and the parachute slides in the opposite direction. This is most desirable when selecting a suitable landing spot and overcoming wind drift. The speed of descent increases when this is done and should not be attempted when close to the ground.

Practice or Exhibition Jumps.—In making practice or exhibition descents the "lift off" method may be used to get clear of the aircraft. The aviator gets in position on the trailing edge of one of the wings, being sure to get out far enough to clear the tail surfaces or any other obstruction directly in the rear. Care must also be taken not to entangle the arms, legs or feet with any of the wires, fittings, etc., of the aircraft. The best position to take is directly behind the farthest out rear strut.

While in the correct position the air chute is released by a jerk on the pull ring. The chute will fill with air and the aviator is lifted off the aircraft directly to the rear and in the line of flight. This method is frequently used in the air forces of several governments to train and familiarize the flying personnel with the use of parachutes.

Practice or training jumps should be made over a suitable field and when weather conditions are favorable. If in the vicinity of water, the jumper should wear a life preserver and provision be made beforehand for his rescue.

The position of the aviator in the harness while descending is similar to that of sitting in a swing. Although not absolutely necessary, it is well to get faced into the direction of drift during descent as a better landing can then be effected. To do this, grasp a handful of shroud lines, as when desired to side slip, and pull the edge of the air chute down about three feet in the direction it is wished to turn, then with the other hand grasp a handful of shroud lines on the opposite side, and without pulling down on them, give a vigorous twist or swing to the air chute in the direciton it is wished to turn, the object being to spin the air chute around. For the same reason as in side slipping, this should not be attempted too close to the ground.

Tendency to Oscillate.—Any tendency to oscillate, or swing back and forth as a pendulum, can be checked by pulling down vigorously on the shroud lines on the high side of the air chute as the body swings in that direction. The instant you start on the reverse swing, release the shroud lines on the one side and meet the swing by pulling down on the opposite shroud lines as you come up on that side.

When Nearing the Ground.—Upon nearing the ground and preparing for a landing, keep a sitting position in the harness but with the knees lower than the hips. Relax the muscles, grasp the lift webs over the head, and right at the instant that the feet touch the ground and before the air chute can collapse, lift yourself up briskly by pulling down on the lift webs. This will help considerably in absorbing the landing shock. Nothing can be gained by lifting the body before the feet touch the ground as the landing impact in this case would only be delayed and not lessened. Do not attempt to

stand up; keep the muscles relaxed, sink in a loose position on the ground and roll if necessary. The shock of landing is about equal to that of jumping from a height of five feet.

Landing in Water.—If it is seen that a landing is going to be made in a body of water, settle well back in the harness and unsnap the leg straps; when nearing the water unsnap the breast snap and take your arms out of the shoulder straps; when three or four feet over the water drop out of the harness into the water. The instant that the body weight is removed from the air chute its descent will be checked and it will drift off with the wind.

Release from the harness can thus be readily and quickly effected, and the dangers of so-called "quick release" devices are eliminated. If using a training outfit, the chest pack may be lifted over the head during descent and allowed to rest upon the shoulders, thus permitting quick removal of the harness as described in the foregoing paragraph.

Landing in a Strong Wind.—When landing in a strong wind the same procedure can be followed as when landing in a body of water, although of course the passenger should wait until his feet touch the ground before getting free of the harness. The air chute may also be collapsed after landing in a high wind by pulling in a handful of the shroud lines a distance of eight or ten feet toward the body, which spills the air from the air chute and flattens it out.

To prevent any possible damage to the chute, never drag the canopy over the ground; fold it over the arm and carry it.

The Caterpillar Club.—There is an organization in which a man qualifies as a member when, in an emergency, his life has been saved by means of his parachute. This does not include jumps for exhibition purposes or pleasure. The caterpillar, letting himself gently to earth by his silken shrouds, has been taken as symbolic of the action of its members and the organization has been called the "Caterpillar Club."

This club is one of the most exclusive, most respected clubs in the world. It has no officers, no dues and no by-laws. Its only requirement to membership is that a jump must have been made from the sky under circumstances that prevented any other means of reaching earth alive. Records of the club are kept by officers of the U. S. Army Air Service. The members include civilians, regu-

lar Army, Reserve, Marine and Navy flyers as well as air mail pilots. Colonel Charles A. Lindbergh is a very prominent member, having made four or more such jumps to date. The club boasts one feminine member, Mrs. Irene McFarland, who saved her life with an army chute when she jumped from a military plane to test a new type parachute that failed to open.

There is no question but what the parachute has done a great deal to promote aviation. It has enabled pilots to reach earth alive to tell of their experiences and what caused the mishap to the plane. With this information aviation engineers can overcome any structural defect and prevent a recurrence. We don't mistrust ocean liners, and very few mistrust a modern airplane, but the presence of a parachute strapped to one's back gives that feeling of security so essential for any commercial enterprise of this nature.

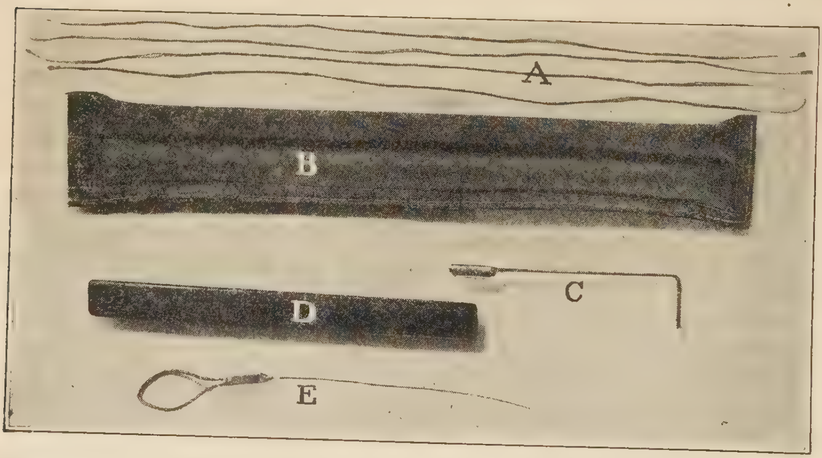

Fig. 148.—Equipment used for packing parachutes (A) Cords, (B) Shot Bag, (C) Packing Hook, (D) Packing Stick, (E) Wire Pin.

Packing the Irvin Air Chute.—For the operation of packing a parachute the following equipment will be found very useful: a table about forty-five feet long by three feet wide, a packing hook, two packing sticks, six shot bags, two wire pins or nails, and several pieces of strong cord about four feet in length.

The table is used as a work bench and should have a clean, smooth surface. Room for a man to work on either side should be provided. Covering the surface with canvas will insure a smooth and clean surface, if drawn tight, tacked and then covered with two or three coats of wing dope.

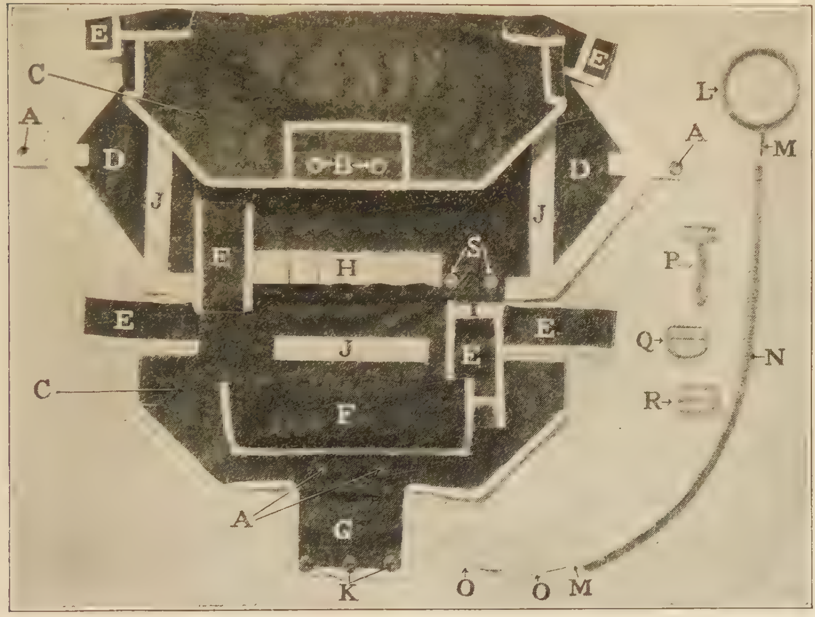

Fig. 149.—Seat Pack Container. (A) Grommets, (B) Locking Cones, (C) Sides, (D) Ends, (E) Corner Flaps, (F) Pilot Chute Flap, (G) Rip Cord Protector Flap, (H) Pockets, for Cordage, (I) Entrance for Harness Lift Webs, (J) Stiffener, (K) Lift-the-dot Fasteners, (L) Pull Rings, (M) Rip Cord, (N) Rip Cord Housing, (O) Rip Cord Locking Pins, (P) Snap, (Q) D Ring, (R) Adapter, (S) Grommets. Harness lift webs are tacked to container with breakable thread at this point.

The packing hook is used when drawing the cordage in the pockets provided for stowing it in the container. A hook can be made from a one-eighth inch piece of hard wire about eight inches long with a right angle bend about one and one-half inches from

the end. The ends should be smoothed with a file so as not to snag the cordage.

The packing sticks are used to tuck in the corners and flaps on the container. They are made from flat pieces of hard wood about fourteen inches long by three-quarters of an inch wide and one-eighth inch thick. They should be tapered down to about one-sixteenth of an inch on one end.

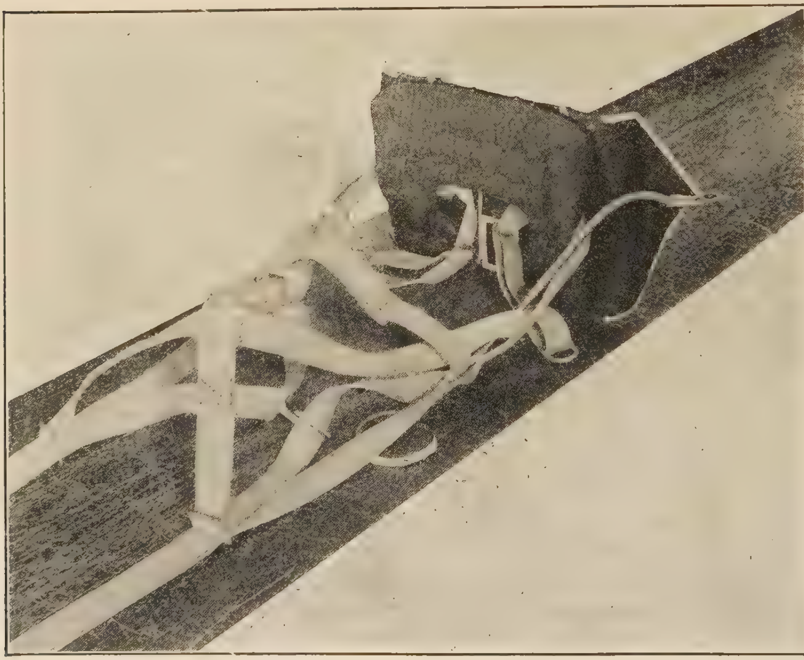

Fig. 150.—Position of harness when laid out for packing seat or back pack.

The shot bags are used to hold the silk panels in place temporarily during the first operations of packing. They can be made from a piece of canvas twenty inches long by six inches wide, folded over the long way and sewed together to form a bag twenty by three inches. A seam should then be sewed down the center to form compartments. Fill this bag with about five pounds of

lead shot and close the remaining open end as tightly as possible.

The pieces of cord are used to help draw the container closed around the air chute. They should be small enough to pass through the holes in the locking cones. Silk cord, the same as that used for the pilot chute shroud lines, is very good for this purpose.

The wire pins or nails are used to slip through the eyelets and hold the container closed temporarily while inserting the rip cord locking pins.

The following directions for packing the Irvin air chute apply to the seat pack but with the exception of a very few variations, as noted, the same directions apply equally well to the chest, lap and back pack.

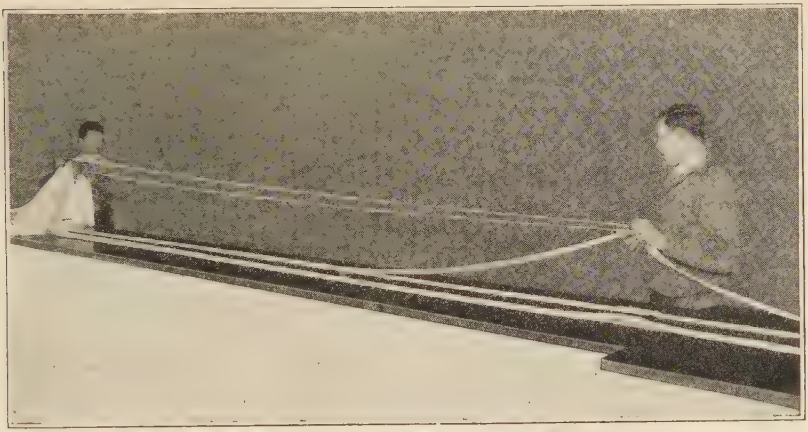

Fig. 151.—Method of checking shroud lines.

The first thing to do is to stretch the chute full length on the table and fasten the peak or vent to one end. If packing a seat pack or back pack, place the rip cord in its housing. In packing the seat or back pack the harness should be placed in the same position on the table that it would be in if it were fastened to the aviator and he lying face down on the table, Fig. 150. For packing the chest pack or lap pack place the harness in the reverse position, or as though the aviator were lying face up.

After the harness and canopy have been placed in the correct

position, make sure that the cords or shroud lines are not tangled. The best way to check this is to trace each line from its place of attachment at the skirt of the silk body to its place of attachment on the harness, making sure that it is in its proper sequence and runs free its entire length, as in Fig. 151.

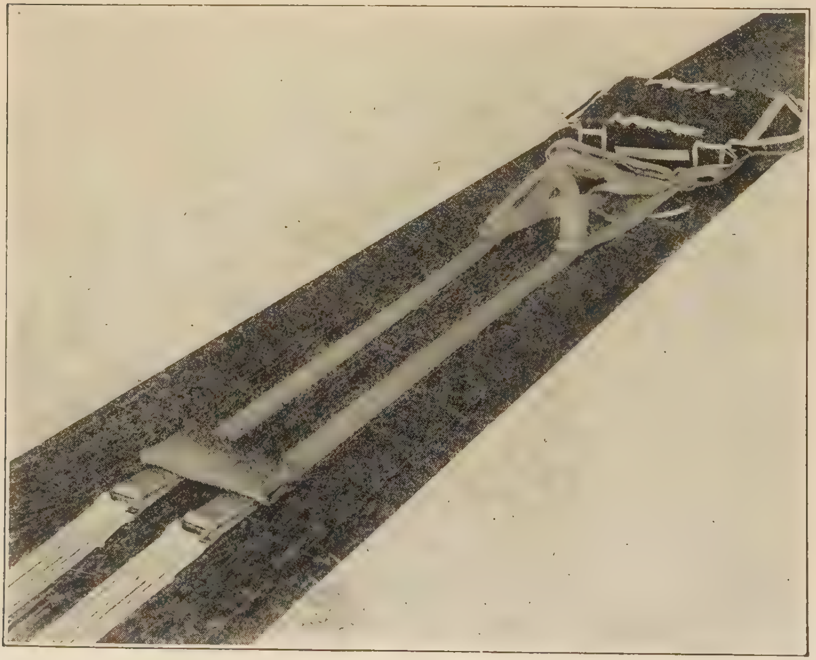

Fig. 152.—Harness held in position with a weight.

After making sure that the shroud lines are clear, grasp the harness (without changing its position) and pull the air chute taut on the table; separate the two respective groups of shroud lines and place a weight on the harness lift webs just back of the *D* rings to hold them in place, Fig. 152.

Next place several shot bags on one group or half of the silk panels or gores which form the main body of the air chute, and

throw the remaining group over and *on top* of the first group, Fig. 153.

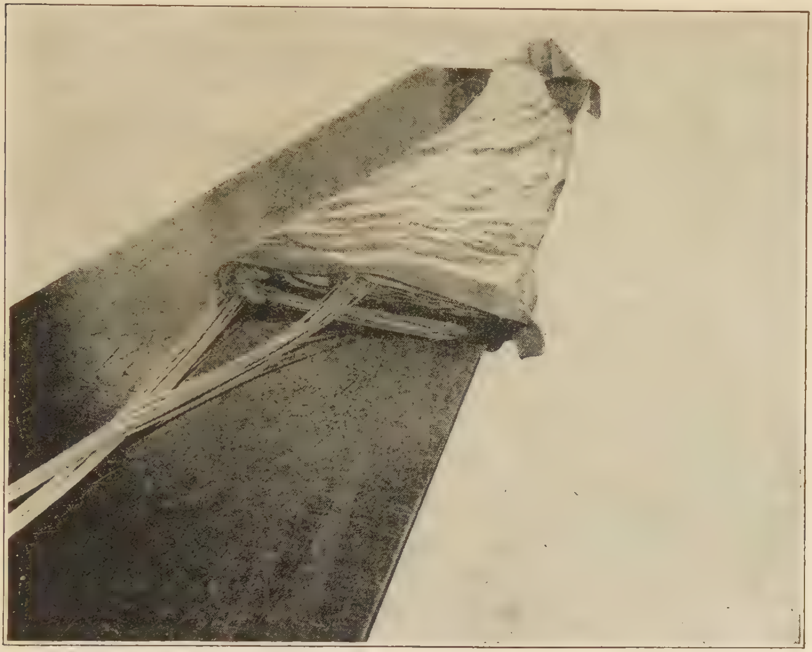

Fig. 153.—One group or half of the silk panels held in place by shot bags; the other group thrown over and on top of the first group.

Next, with one hand, grasp the center of the panel then on top at the skirt and draw it back toward the edge of the table; at the same time with the other hand hold the shroud line in place in the center of the table. Lay this panel on the table and straighten it out all the way to the vent.

Repeat this operation with the next panel, lay it on top of the first panel and straighten out. Fig. 154 illustrates the first panel in place on the table and the second panel being laid in place. Continue this operation until the remainder of this group or half of the panels have been thus folded.

Fig. 154.—Method of folding individual panels; first panel in place on table, second being placed on top of first.

Next remove the shot bags from the unfolded group of panels and place them on the group of panels that have just been folded as shown in Fig. 155.

Next throw the unfolded group of panels over and *on top* of the folded group and fold them in the same manner as the preceding group. After all panels have been thus folded, remove the shot bags.

Fig. 156 illustrates the progress made thus far; the silk body is neatly folded, the shroud lines are together in the center with half of the silk panels on each side.

Next fold one complete group of the silk panels back toward the center of the silk body, as illustrated in Fig. 157 and place on top of the silk body in such a manner that what was their outer edge

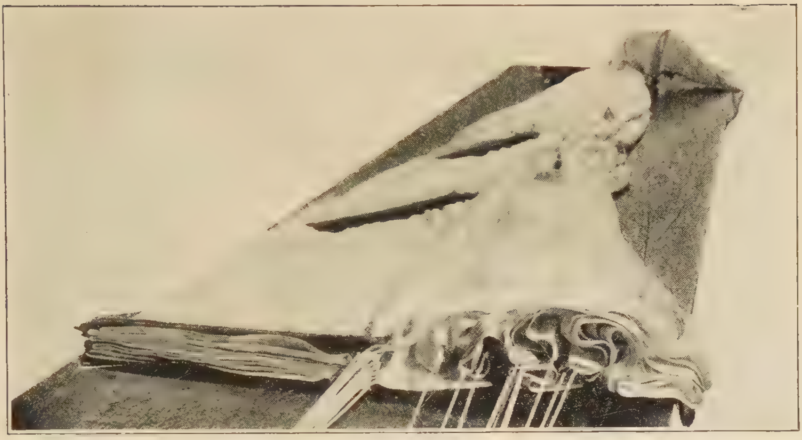

Fig. 155.—One half of silk panels folded and held with weight, remaining half to be folded.

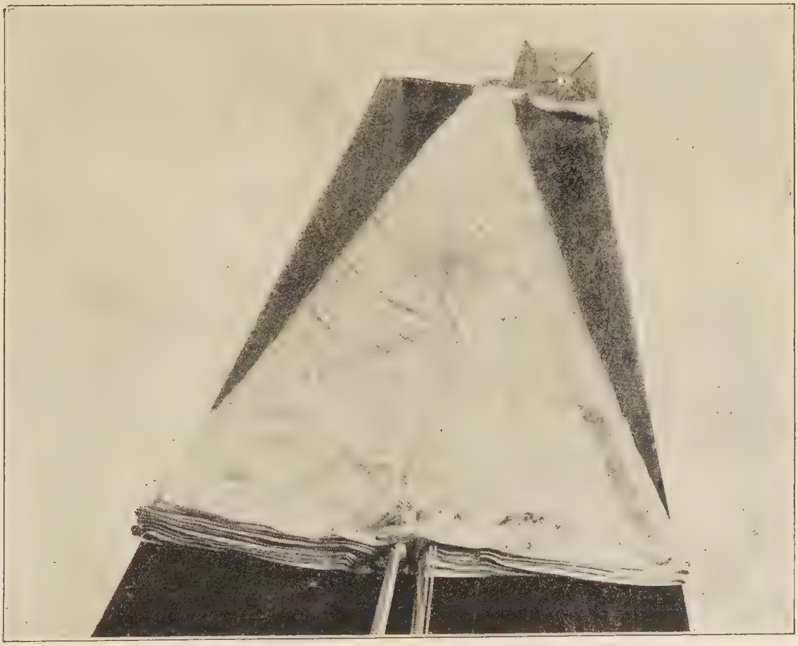

Fig. 156.—Silk body folded. Shroud lines are together and in center with half of panels on each side.

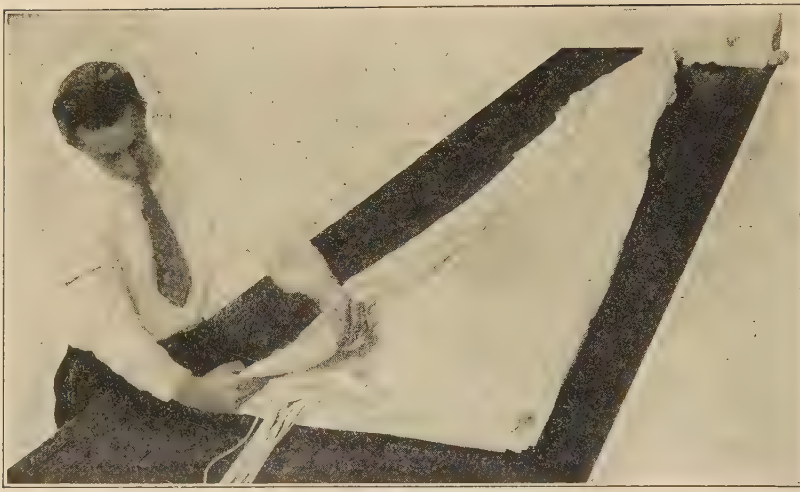

Fig. 157.—Folding one group of panels back onto silk body.

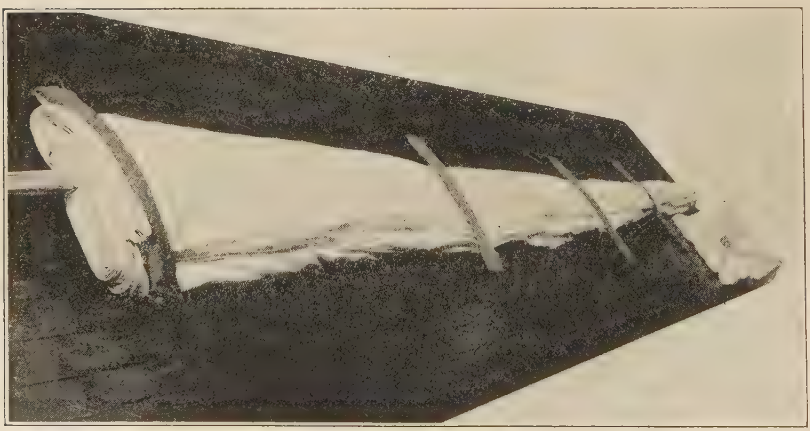

Fig. 158.—Both groups of panels folded back to center and held in place by shot bags.

now comes just past the center of the silk body and overlaps the shroud lines.

Fold the remaining group of panels back toward the center and place on top of the first group. Place shot bags on top to hold them in this position. Fig. 158 illustrates how the air chute should look on completion of this operation.

Next release the vent from its fastening at the end of the table and remove the weight from the harness lift webs. Without disturbing the original position of the harness, turn the lift webs back and place them, on the container on their respective sides, Fig. 159.

Next grasp the shroud lines so that they are even and together in one group and pull the silk body toward the container a sufficient distance to permit a loop of the cords to be drawn into the pocket provided for it. Use the packing hook to draw the cordage into the pocket. Fig. 159 illustrates the first loop in place.

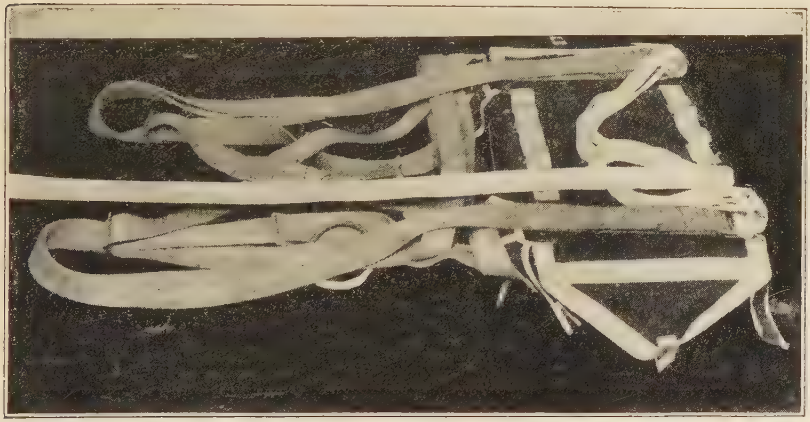

Fig. 159.—First loop of cords in place.

Next grasp the shroud lines as before and pull the silk body toward the container a sufficient distance to permit the second loop of cords to be drawn into its pocket opposite the first loop.

Fig. 160 illustrates the first two loops in place and the third loop being drawn into place.

In drawing the cordage into the pockets, pull the silk body toward the container no further than necessary to permit one loop at a time to be drawn into the pocket. This keeps the cordage taut at all times and prevents possible entanglements.

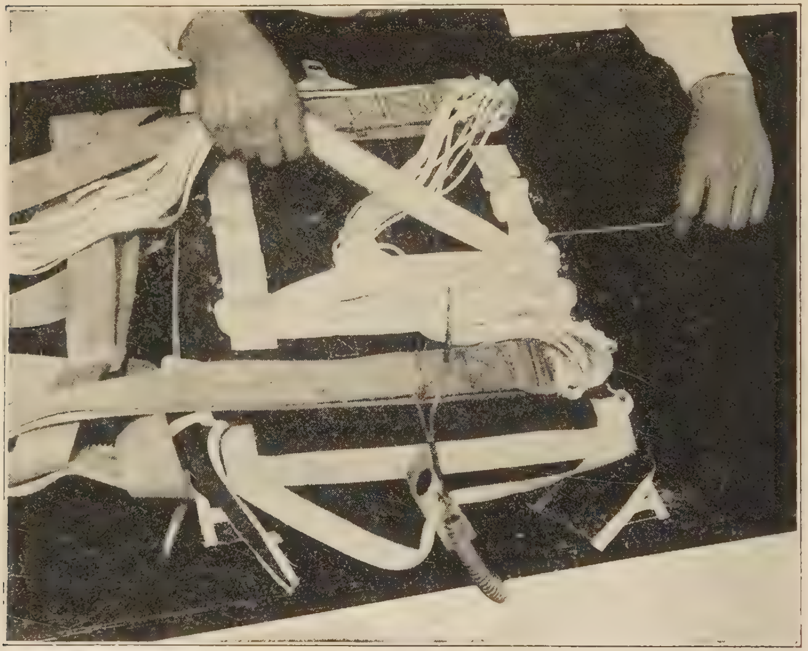

Fig. 160.—First two loops of cordage in pockets; third loop being drawn into pocket.

The function of the pockets is to retain the cordage within the container until after the silk body has deployed, thereby eliminating possible entanglements. If, through long use or for other causes, the pockets should become enlarged to such an extent that they do not hold the cordage firmly in place, they should be repaired or renewed.

Continue the operation of drawing the cords into the pockets until all the pockets have been filled.

Next grasp the harness and container together (so that their position in relation to each other will not be changed) and turn one-quarter way around on the table, which brings the ends of the container in line with the silk body. (This operation does not apply to back packs or training outfits.) When packing seat packs, turn the end of the container to which the rip cord housing is attached away from the silk body. When packing lap packs either end of the container may be placed next the silk body.

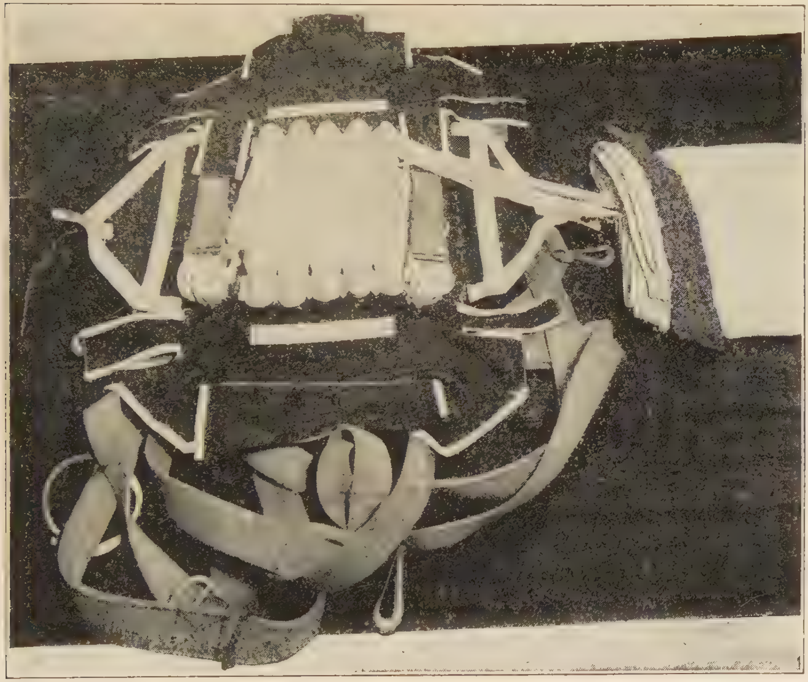

Fig. 161.—All cordage pockets filled and container given one-quarter turn from its original position. Rip cord housing on end farthest from silk body.

Arrange the flaps at the corners of the container.

The next operation will be the folding of the silk body onto the container. Grasp the silk body at the skirt, being careful not to disarrange the folds, and pull it toward and over the container, at

the same time placing any surplus cordage neatly back and forth crossways of the container and on top of the cordage that is in the pockets.

Place the silk body on the container so that the folded skirt or outside edge comes just to the edge of the wire frame in the bottom of the container, Fig. 162.

Fig. 162.—Method of folding silk body into container.

Next, while holding the first fold of the silk body in place on the container, draw up the remainder of the silk body a sufficient distance to permit a second fold to be placed on top of the first fold. Fig. 162 illustrates how this operation is carried out; the first fold is in place on the container and the second fold is being put in place. Continue this operation until the entire silk body has been thus folded on to the container. Each fold should be the same length and width as the bottom of the container. Remove the shot bags as the silk body is folded onto the container. Take care that no shot bags are enclosed within the container.

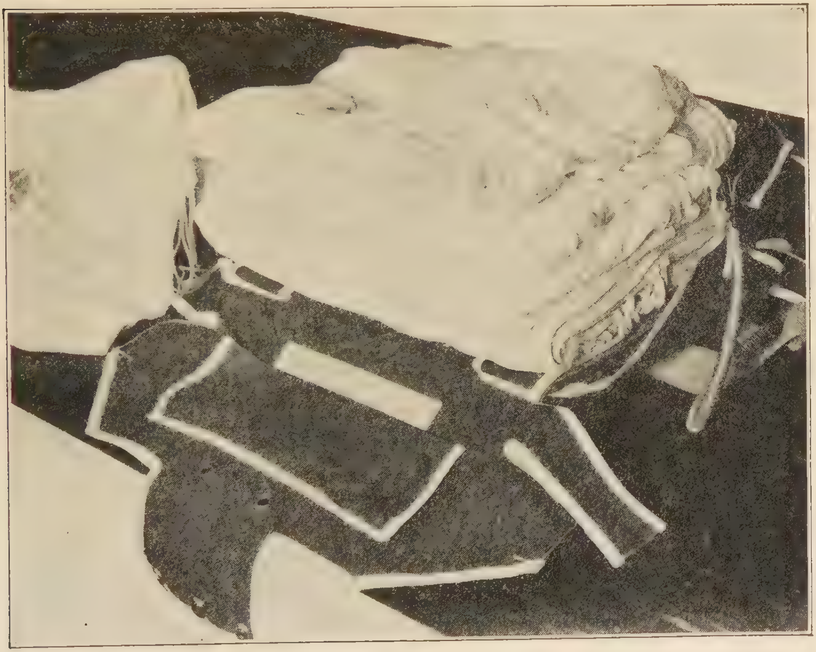

Fig. 163.—Silk body folded and ready for enclosure within container.

Fig. 163 illustrates the progress made thus far. The silk body is folded and ready to be enclosed within the container. Note that the pilot chute extends from the container on the end opposite that from which the rip cord will enter. In closing the container the pilot

chute is always inserted after the two sides and one end have been closed. On seat packs and back packs the end of the container on which the rip cord housing is attached is closed first, therefore in the next operation of closing the container take care to leave the pilot chute out on the end opposite that from which the rip cord will enter.

On lap pack containers the rip cord enters from the side, therefore either end may be closed first. However the pilot chute is inserted from the end which is closed last. (The chest packs on the training outfits have no pilot chutes.)

Next insert a piece of strong cord through the hole in the top of each locking cone. These cords should be about four feet long and small enough to permit the additional entry of the locking pins into the holes in the locking cones.

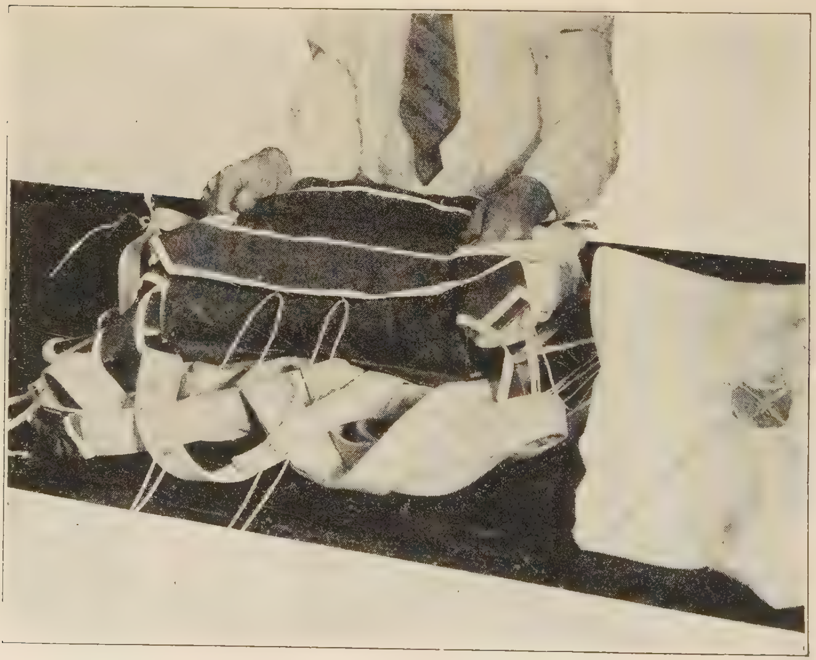

Fig. 164.—Pilot chute flaps overlapped.

Next draw together and overlap the pilot chute flaps on the container. The flap on the side to which the locking cones are attached should be on the bottom. Fig. 164 illustrates the pilot chute flaps properly overlapped. Their function is to keep the pilot chute separated from the main body of the air chute while in the container.

Next draw the sides of the container together and with the aid of the cords previously mentioned, pull the locking cones up through the grommets and secure in place temporarily by inserting a nail or wire pin of suitable size through hole in each locking cone. Do not remove the cords. Fig. 165 illustrates sides of the container closed and held in place temporarily by wire pins.

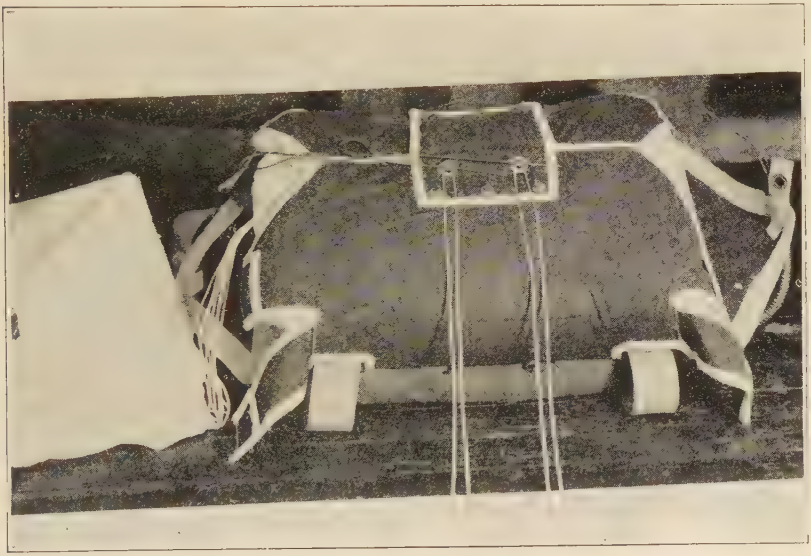

Fig. 165.—Sides of container closed, pilot chute still out at opposite end from which rip cord will enter.

The closing of the ends is the next operation to be carried out. Before proceeding further make certain that pilot chute flaps have not become disarranged and are properly overlapped and straightened out.

Insert both cords through the grommet on the end to which the

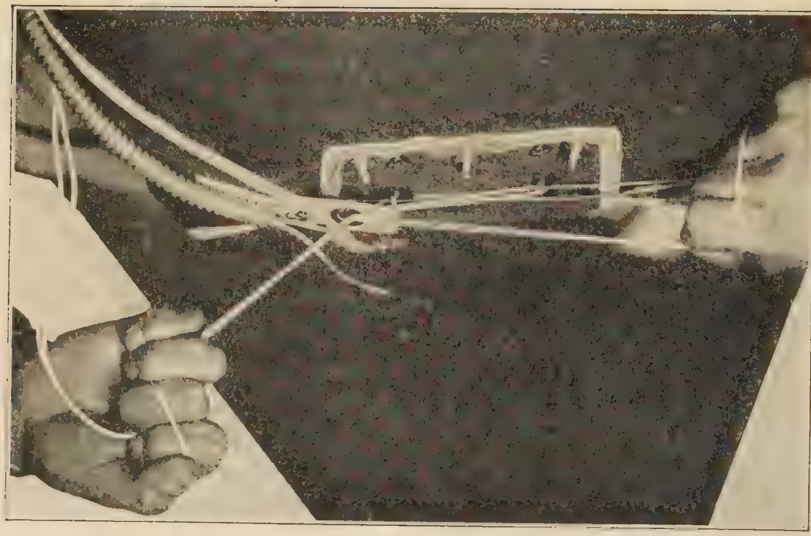

Fig. 166.—Closing the end.

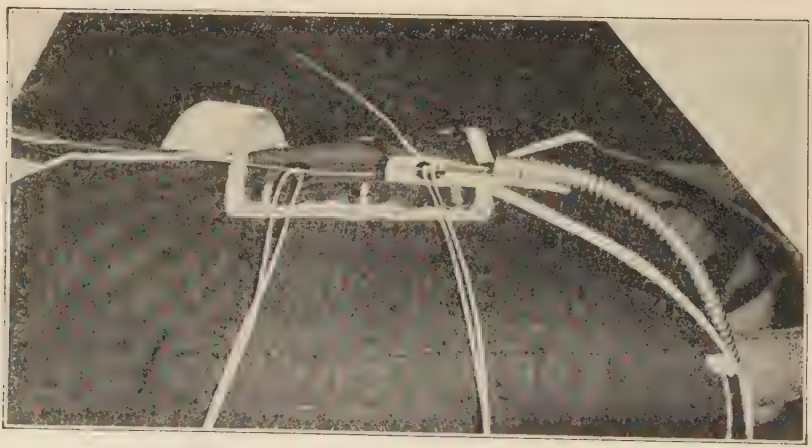

Fig. 167.—One end closed, rip cord locking pin in place. Cords have not been removed from cones.

rip cord housing is attached and draw it up into place over the locking cone. Remove the temporary pin from cone, draw cone through grommet and insert proper rip cord locking pin into hole in cone.

Fig. 166 illustrates how this operation is carried out; Fig. 167 illustrates the operation completed. Note that cords have not been removed from cones.

Before proceeding further look at the open end of the container and see if any of the silk folds have worked themselves out beyond the edge of the bottom of the container. If so, push them back in. The container will close easily if the silk body has been folded to the same length and width as the bottom of the container.

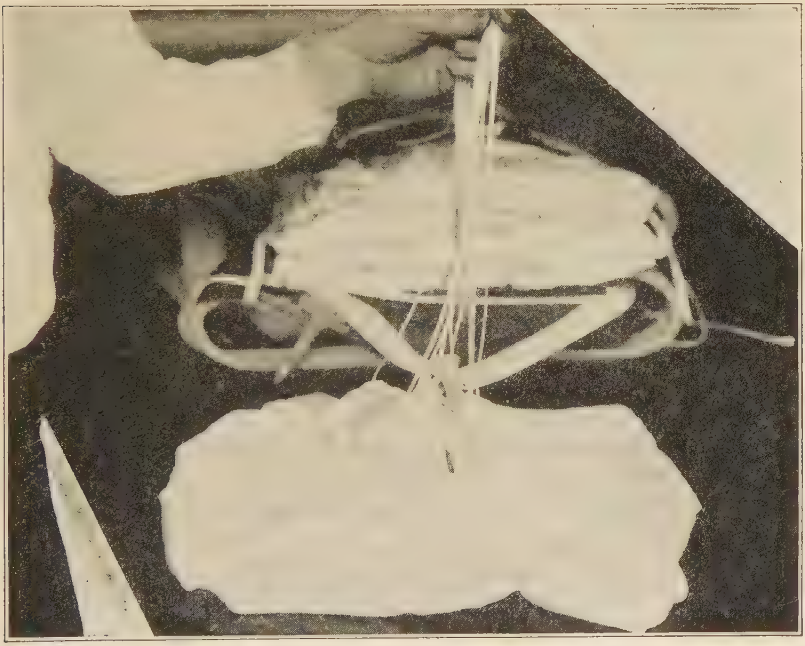

Fig. 168.—Method of folding pilot chute.

The next operation consists of folding the pilot chute and inserting it into the container. Make certain that pilot chute shroud lines are not entangled. Lay the pilot chute on the table and allow

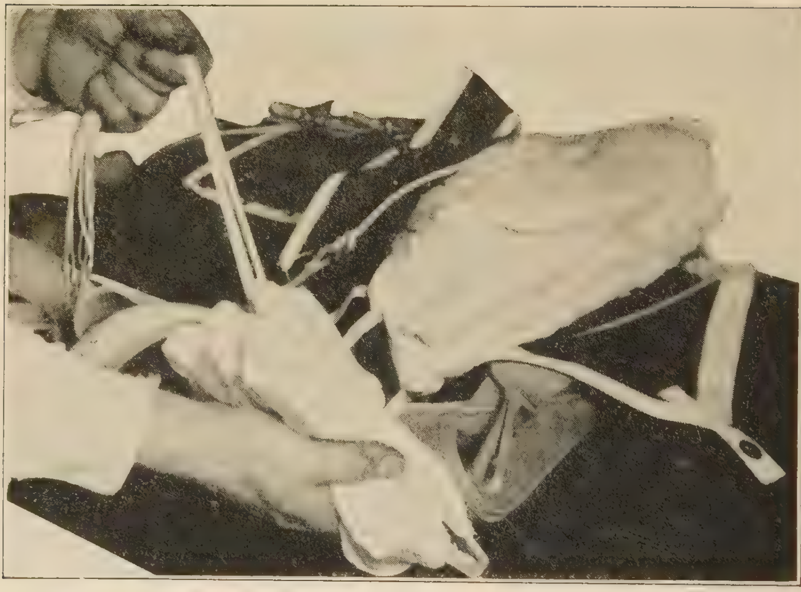

Fig. 169.—Pilot chute folded and ready for insertion into container. Shroud lines are kept extended during entire operation.

the outer circumference edge to fall inside and to the center, at the same time keeping the shroud lines extended above the pilot chute as illustrated in Fig. 168.

With the outer circumference edge turned inside, fold the pilot chute by compressing the spring, at the same time keeping the shroud lines extended as before. Fig. 169 illustrates the pilot chute properly folded.

Next insert the pilot chute *peak first* into the container *on top* of the *uppermost* pilot chute flap as illustrated in Fig. 170. Tuck the surplus pilot chute cordage neatly under *bottom* pilot chute flap.

Fig. 171 illustrates the pilot chute in place with surplus cordage folded and tucked under the bottom pilot chute flap.

Next close the remaining end of the container by inserting both cords through the grommet and drawing the end up and over the locking cone in the same manner as illustrated in Fig. 166; remove

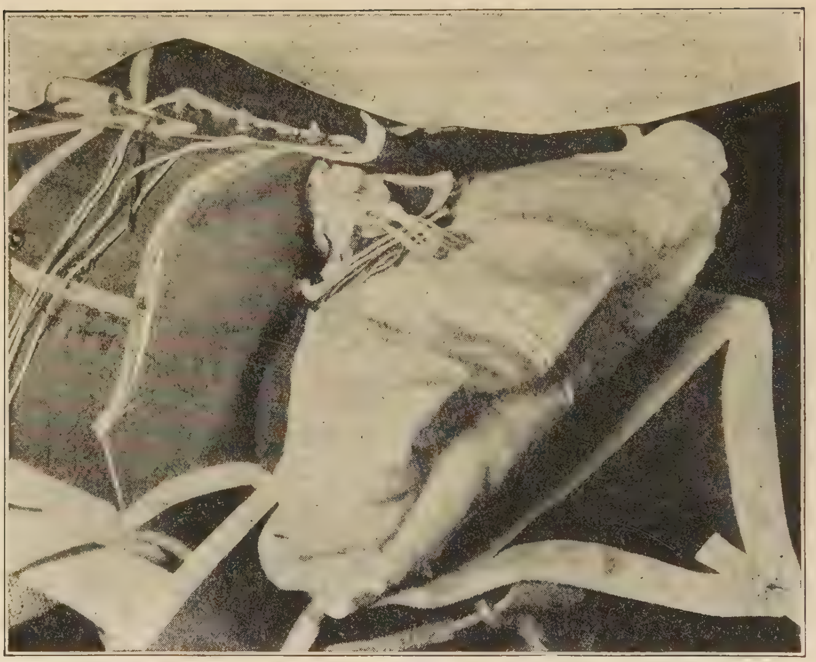

Fig. 171.—Pilot chute in place; surplus pilot chute cordage stowed underneath bottom pilot chute flap.

is too strong, as this would likely make it difficult for the aviator to pull the rip cord free from the locking cones.

Pass a *single strand* of the thread under the outer rip cord locking pin and on the outer side of the locking cone and secure behind the locking cone by half hitches around the rip cord wire. This is done merely to prevent the rip cord locking pins from working themselves out of the locking cones and does not delay or prevent the removal when a deliberate pull is applied to the rip cord, provided a thread has been used that is not too strong.

Fig. 172 illustrates the air chute properly packed, opening elastics hooked in place, rip cord safetied, and rip cord protector flap ready to be snapped in place.

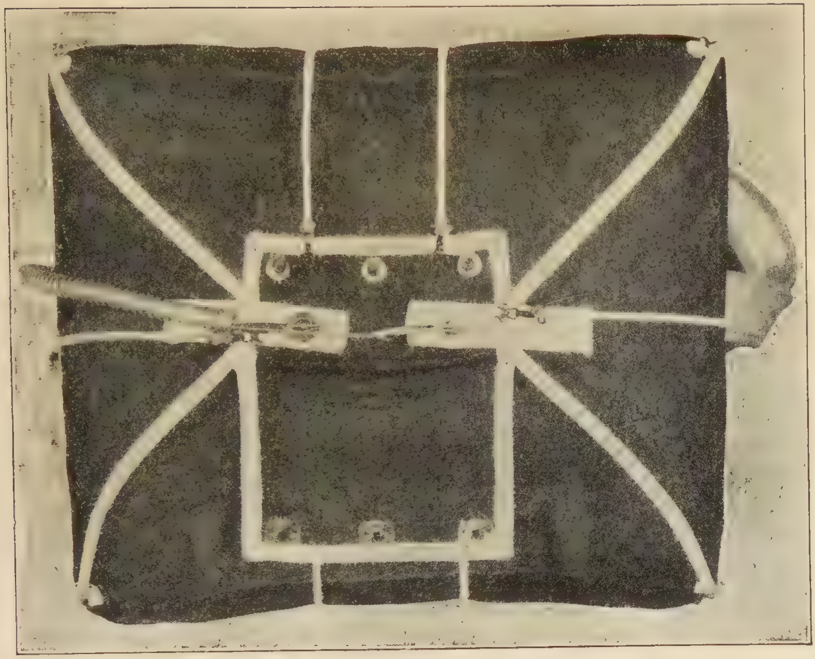

Fig. 172.—The air chute packed with the exception of folding down and snapping into place the rip cord protector flap.

Apply a very thin coat of vaseline to rip cord locking pins and snap the protector flap in place over them.

Next adjust the harness to the size of the aviator who is to wear it. When fastening the harness to the person the snaps are snapped *toward* the body. After adjustment tack the harness lift webs to the shoulder and back straps with a breakable thread of about twelve or fifteen pounds tensile strength. This is to prevent the lift webs from flapping about and annoying the aviator while in flight. See Fig. 173 *A* and Fig. 174 *A* and *B* for tacking harness in place.

Tacking the harness lift webs in place with breakable thread does not in any way delay the proper operation of the air chute as the threads are broken during the opening. The lift webs are also

Fig. 173.—Front view of seat pack showing stitches to hold harness in place after adjustment to the size of the aviator.

tacked to the bottom of the container with breakable thread at point *B*. This prevents lift webs being pulled from place by an accidental jerk on them. Take care when tacking at this point not to run thread through the silk body of the chute.

Fig. 174.—Rear view of seat pack showing webs tacked with breakable thread to (A) the shoulder and back straps, and (B) to the container.

Testing Air Chutes.—Unless thoroughly familiar with packing and having had considerable experience, it is best to test your first three or four packing jobs by dropping the parachute with a weight

or dummy attached to see if you have done the work properly and the chute opens as it should.

For testing purposes a dummy should be constructed of about the size, weight and flexibility of a man. In testing the Irvin air chute it should be remembered that the harness is so designed that, when strapped to the body, the opening shock is taken on the "seat strap." The dummy should be so constructed, therefore, that its weight comes on the seat strap and not on the leg straps.

Airplane for Testing.—Testing can be done to the best advantage from a bombing airplane or some other large aircraft, the construction of which will permit the dummy being suspended full length by the head and within the fuselage. A bomb release or some similar device that can be operated by the pilot should be rigged up on which to suspend the dummy.

Operation of the air chute after the dummy has been released from the aircraft is effected by the use of a "static lanyard" or strong piece of line approximately six feet long and of eight hundred or nine hundred pounds tensile strength. One end is securely fastened to the aircraft and the other end to the pull ring on the air chute.

When packing Irvin air chutes for test by this method the rip cord should *not* be run through the rip cord housing, as the pull applied to the rip cord by the static lanyard as the dummy falls away may tear the housing loose from its anchorage to the harness.

Care must be taken when suspending the dummy within the fuselage to dispose of the static lanyard and loose end of the rip cord in such a manner that the air chute will not be accidently released before the dummy has dropped below the aircraft.

CHAPTER XX

HOW TO LEARN FLYING

THIS chapter has been written primarily for the guidance of instructors who teach embryo pilots how to fly, but it may be read with advantage by the pupils themselves in order to recognize proper training methods, what to expect and what is expected of them.

The main object of flying instruction is to teach a man to fly his machine instinctively, not by the one-two-three method of figuring out the why and how of each movement beforehand. If a person flies instinctively he very seldom gets into serious difficulty; he has time to read his map and instruments on cross-country flights, or can accomplish a forced landing easily and without fear of accident.

It is not necessary to point out the necessity of increased efficiency in the air at this time of increased aërial commerce and transportation. It might be well to mention the principal causes which account for the demand for greater efficiency. Roughly speaking these are:

Shortage of pilots with necessary experience and time in the air to handle the commercial air carriers of established air lines.

High value of individual efficiency in the air in order to fly on schedule and under any conditions.

The casualties and wastage resulting from: (1) Bad flying, due to ignorance, when operating with passengers and freight over an established route to be flown on schedule; (2) Inability to decide instantly upon the proper thing to do in an emergency.

Increased efficiency means fewer casualties, greater success, firmer establishment of aviation in the minds of the public and progressive growth.

It cannot be emphasized too strongly that confidence in one's ability and high morale is the basis of successful work in the air.

It is more necessary in teaching flying than in any other form of instruction that the instructor have a knowledge of his pupil's character and temperament. Most pilot pupils are, as a general rule,

so young that they are very amenable to influence, especially through their instructor in whom they should place the utmost confidence. For both these reasons an instructor can teach his pupils successfully only if he is in very close touch with them, knows them well individually, and can, by his own personal influence, inspire them with high spirit and morale.

It is not learning to fly when a pupil just puts in so many hours in the air. Unless he learns something each and every time he goes up, valuable time is being wasted and the pupil does not progress. For this reason a course incorporating time serving or a time limit is not satisfactory for either school or pupil. Some persons can learn to handle a ship satisfactorily in from six to eight hours in the air, while others may require twice that much. Of course it costs more to teach the one requiring more time, but spread over a number of pupils, the cost will average up and a much better reputation will be acquired for the school and instructor than if all students, regardless of aptitude, were given just so many hours of instruction.

Both instructor and pupil should realize that although it is possible to break a machine up while in the air through misuse, a course in flying instruction can be made as safe as a course in automobile driving. This safety depends upon a very thorough method of instruction in which the pupil should acquire all the knowledge necessary to enable him to handle any ordinary emergency which might arise in the air, and which will leave no possible doubt in his mind as to what action to take when anything unusual happens.

It might be well to mention here some of the terms used for the enlightenment of those not familiar with flying. A machine equipped with two sets of controls, interconnected and operating simultaneously, one set in each cockpit, is used for instruction purposes. This type of ship is said to be equipped with dual (or double) controls. When a pupil is being instructed in this type of ship by an instructor he is said to be taking dual-control instruction. When the pupil flies alone, in complete charge of the ship and operating the controls himself, he is said to be flying "solo." When he is told how to execute some maneuver while on the ground and then goes up to do it, he is said to be taking solo instruction.

The old war-time method of instruction was to give a man dual instruction until such time as he could take the ship off, land it, and execute turns satisfactorily, then turn him loose in solo and let him gain experience flying alone. It has been found much more satisfactory to sandwich in dual instruction with the solo, however, in order to correct errors noticed by the instructor who watches from the ground.

Acrobatic or stunt instruction is a very necessary part of modern flight instruction, not for the thrill and pleasure, but for the confidence instilled and the knowledge of how to recover from awkward and unusual positions. This is absolutely necessary if a pilot is to handle commercial ships and fly in all kinds of weather, wind, storm and sleet. The winds that usually accompany such bad weather do peculiar things to the equilibrium of an airplane, and whether or not it is desired, one finds himself very often in a state of acrobatics as a consequence. They should not be taught, however, until the pupil has demonstrated his ability to fly straight, make normal turns and landings and otherwise show that he is thoroughly familiar with control of a ship under ordinary conditions. A crash or accident has a most demoralizing effect on a pupil, especially if it is experienced in the early stages of his instruction. For this reason, also, he should not be sent on a cross-country flight too early. As a preparation for this type of flying, instruction in forced landings, while still taking dual instruction, should be commenced early. Several small fields near the airport should be selected for this and used occasionally by the instructor.

Don't forget for a minute that straight flying in ideal weather is just about as simple as driving an automobile down an open road. It is the instinctive knowledge of what to do in emergencies, quick thinking and doing, coördinated, that make a pilot either expert or mediocre.

As for instructors, the greatest attention should be paid to the general effect they have on their pupils and to their efficiency in instructing. The latter can best be judged by their expertness in the air, by their ability to analyze every maneuver, and above all, by their ability to explain it clearly so that the pupil understands. This will all be reflected in the morale and spirit of the students.

Confidence.—Half the battle of instruction is won when the pupil

is instilled with confidence. The first thing to do, therefore, is to clear his mind of any preconceived ideas that flying is dangerous. This can be done most easily by the evidence of his own eyes. Nothing will undermine his confidence more than the sight of crashes and injured pupils. For this reason *there must not be any.* New pupils should be encouraged to mingle with and become well acquainted with the other pupils, especially those well advanced in their training. In this way they gain confidence in their own prospects by talking over experiences with those who have already been "through the mill," so to speak. They will learn that they have no obstacles to overcome that have not been presented to everyone. The pupils will talk their experiences over with each other in their own language and with much more intimacy than with an instructor, although the instructor should encourage these confidences from his pupils.

The words "danger" and "nerves" must not be a part of an airman's vocabulary. Refer only to the "right" and "wrong" way—never to the "safe" and "dangerous" way. Nothing that a pupil or flyer may do in the air is dangerous if he knows what he is doing, what the result will be and how to regain trim, or an even keel. The great majority of accidents are caused through ignorance or carelessness, and if, instead of telling an embryo that a maneuver is dangerous, he is taught how to do it properly, his instinct of self-preservation will take care of him. In line with this thought is the following rule, well worth remembering: The pupil should be taught the right way to execute every maneuver possible with a ship, but he should also be *shown* the wrong way in order to demonstrate the results from carelessness or ignorance. For instance, there is a right way and a wrong way to make a turn, and if taught the right way, the pupil will learn that a correctly executed turn is just as safe near the ground as high up. This might become absolutely necessary to do some day and confidence will permit its being done successfully. The pupil should be told the solution of all likely difficulties during his initial instruction and before he has a chance to become involved in them. Therefore he should be taught how to fly and what to do in case of sudden engine failure, together with how to pick and land in a small emergency field, before he is allowed to go on his first solo.

Instructors.—That teaching successfully depends more upon the teacher than upon the pupil is a fact which very often appears to be overlooked. Since pupils depend entirely upon their instructors to teach them all there is to know about flying, and to teach them correctly, first attention should be concentrated upon the efficiency and previous training of the instructor. A thorough knowledge of theory and practical flying is not all that is required of an instructor. He must be able and apt in explaining clearly and in an easily understood manner this knowledge to his pupils. As said before, he should be a good fellow, a mixer and one to inspire confidence. He should know intimately all pupils under him, their temperament and peculiarities, and for these reasons should not attempt to instruct a class of over six students at one time. He should also retain his class all the way through their training rather than switch pupils from one instructor to another. If a student is forever having to become acquainted with a new instructor for each stage, both of them lose the intimate personal contact so necessary to smooth, quick learning.

Dual Control Instruction.—The act of flying is not included among natural human instincts and cannot be learned successfully by self-instruction. Therefore, it must be taught and taught very thoroughly and carefully. This can be done only through a great deal of dual-control instruction and only after the methods have been carefully studied and thought out.

One very important rule to apply in dual instruction is that the pupil should ride in the cockpit and seat that he will occupy when he flies alone. He should not be taught while riding in the passenger's seat. It is essential that the dual-control instructing machine be supplied with some means of communication between instructor and student, either speaking tube or telephone, and that both may use it satisfactorily. Instructions or corrections should be given by the teacher in a soft, even, steady voice, never harshly or excitedly, no matter in what position the pupil has placed the ship. If the instructor keeps cool and calm, the pupil is influenced to do likewise. The reverse holds true, also.

The secret of success in teaching dual is to make the pupil realize that he has complete charge of the ship when he is handling the controls at the instructor's orders. This can be accom-

plished by the teacher placing his hands in sight on the cowling. Whenever the pupil is practicing or attempting any maneuver the instructor should not touch the controls until absolutely necessary, and should show the pupil that he is not touching them until the pupil has exhausted all is own efforts and solutions of the difficulty, provided the execution is faulty. The length of time necessary on dual instruction will be materially cut down if this rule is observed and the pupil allowed to control the machine acting on the directions given by the instructor over the communication medium.

Before attempting actual flying and instruction in the air any beginner should have a ground training through reading or lectures. He should learn here the use and effect of the various controls, how to use the horizon as a guide to level flight, how air acts on wing surfaces, about engine principles, their controls and operation, how to recognize engine trouble by sound, and various other matters that can just as well or better be taught on the ground than in the air. A very good system is to take new pupils to the surrounding emergency landing fields and let them see how others land and take off. Watching the flying going on at the main field and criticizing or remarking about the landings and turns being made is also helpful. All of these things will save time in the air, which is more or less expensive compared to ground instruction.

Just as soon as possible after arrival at the school, a pupil should be taken for a flight to see how he takes to it. It is better for all concerned that he give up flying aspirations immediately if he is subjected to airsickness, dizziness or other physical disabilities instead of having to give up after wasting much valuable time and money. It is not advisable to indulge in acrobatics or stunts with a pupil on his first ride. I always take them for a nice joy ride, letting them enjoy it fully if possible. A man's confidence can be destroyed very quickly if he is at all nervous. On the other hand, one is more likely to gain confidence and become a very satisfactory pilot, if flown quietly at first, and allowed to become used to the feel of the air and the sensations experienced.

First Instruction Flight.—Instruction should commence and continue in any weather in which the instructor himself can fly. The idea of waiting for calm, clear skies lessens confidence and does not at once prepare the pupil to handle himself in rough weather.

A fellow can learn more about controlling a ship in ten minutes of rough-weather flying than he can in thirty minutes of calm-weather flying. Some instructors favor climbing up through the bumps near the ground until smoother flying is found at high altitudes and there allowing the pupil to take first control. The pupil should then be told merely to keep the ship headed straight and on an even keel. He should be able to do this satisfactorily within the first few minutes. If after a reasonable period and a little instruction he is still unable to keep the ship level and straight, it is improbable that he will ever make a real pilot.

Effect of Controls.—As soon as the pupil can fly the ship straight he should be told to move the controls smartly in any manner he wants—wobble them a bit, as the saying is. This is for the purpose of showing him what effect the controls have under these conditions, and it should be insisted upon that he does wobble them, also that he is not afraid to do so. It will then be demonstrated how very little movement of the controls is necessary for ordinary control, but how much is necessary for decided reaction.

The controls of the instruction ship should not be too sensitive but should require average pressure to move them, and the ship should respond easily. The student should be impressed with the need of cultivating a delicate touch on the controls and how not to overdo it. He should be taught that it is not necessary to hold the controls in a rigid grip, keeping them from moving slightly, but that they act rather like those of a boat and can be moved slightly and freely about without materially affecting the trim of the ship.

Teach them that if right aileron is applied, left aileron must be applied to return the ship to level laterally. Likewise if right rudder is applied, left rudder must be used to return the ship to its original direction of flight, returning it to neutral will result only in the ship assuming a new direction.

Level Datum.—As mentioned in Chapter XVII, there is some point on the forward part of the ship which, when lined up level with the horizon, will indicate the level flying position of the ship. It does not necessarily have to be the valve rocker arms, it may be any part of the cowling. A rule to remember is that with engine on, this point should be on or above the horizon and with engine off, when it is necessary to glide to keep flying speed, the datum point

should be below the horizon. The machine can be kept level laterally by keeping an equal amount of ground showing between each wing tip and the horizon.

Turns.—As instruction progresses the instructor should first execute the maneuver himself and the pupil should watch the movement of the control levers. After the pupil has demonstrated his ability to fly level and straight he should be shown how to execute a turn, starting with a normal bank. The correct coördination of the rudder and ailerons is essential here in order to produce a properly banked, no-slip, or skidding, turn. It may be explained at this stage that when a wind is felt on either side of the face, the ship is slipping in that direction and correction should be made for it. When the pupil is capable of holding the ship in a normal bank for some time without throwing the nose up or down, allowing it to side-slip in either direction, he can pass on to steep banks, finally reaching the vertical bank.

It is assumed that the pupil has been shown on the ground how the rudder and elevators exchange functions as the ship is tipped farther and farther on its side. As the angle of bank increases, up rudder must be applied to keep the nose from drooping and the stick pulled well back in order to maintain a circular path.

Turning should be allotted first place in the sequence of flying instruction. It is common and serious mistake, I believe, to try to teach landing before the pupil is thoroughly familiar with the controls and has begun to grasp the "feel" of the machine. Turns, glides and simple stalls should be taught before landing instruction is commenced, and then continued all through the course. Absolute accuracy on turns, whether near the ground or at an altitude, takes a long time to develop and continued instruction on them should be kept up throughout the training period, but the pupil should have at least grasped the right idea about turns before starting on landings. Most everyone develops a preference to turn in one direction or the other. This tendency should be immediately checked and overcome. The ability to turn quickly and naturally in either direction may in itself be sufficient to enable the pilot to save his ship in some emergency. It is also necessary when taking the examination for commercial pilot's license.

The turn should be taught as a combination of bank and rudder

and in order to visually demonstrate this, bank the ship without applying rudder and show how it will side-slip. Then apply rudder without bank and show the resulting skid, and if continued, the spin. The pupil should be shown how to bank over and then apply enough rudder to keep the datum point on the horizon. In the steep bank show how the top rudder must be applied to raise the nose to level, and bottom rudder applied to lower the nose to level, using the stick only to control the tightness of the turn.

When a machine is turning it has a tendency to over bank, because the wing on the outside of the turn travels faster than the one on the inside, providing more lift on the one wing than on the other. For this reason keeping the stick in its neutral position does not always prevent over banking, and occasionally a little opposite aileron control is necessary. Pupils found to have difficulty in keeping the ship steady on the horizon should be made to seesaw the rudder during the maneuver which results in an exercise very similar to practicing the musical scales on a piano—practice makes perfect.

The fundamental method of turning every machine is the same, but the proportionate amount of rudder necessary will vary in almost every case. The direction of turn will have some effect on the manipulation of the controls due to the torque exerted by the engine, it helping in one direction and tending to prevent in the other.

Beginners will continue to make turns incorrectly until they have learned to combine rudder and aileron control properly, their chief faults being to commence a turn with too much rudder and not enough bank; allowing the datum point to drop below the horizon; not pulling the stick back far enough, or over-controlling altogether by pulling the stick all the way back and applying the rudder roughly—which might result in a spin.

Leveling out after Turn.—The usual instinctive way of recovering from a turn is to apply opposite bank and straighten the rudder. This often requires effort to force the stick over against the bank. For this reason a great many pilots straighten out from a turn by applying bottom rudder smartly, causing the nose to fall, then pulling back on the stick to raise the nose to level again. The application of bottom rudder in this case must be timed to occur ninety degrees before the turn is to be finished, at a time when

the ship is headed at right angles to the ultimate desired course.

Gliding.—A ship of the commercial type will glide, with power off, at a much lower speed than the ordinary cruising speed and it is essential that the pupil become familiar with the slowest speed at which the ship will glide and still maintain flight and control.

The ordinary gliding angle is about five to one, that is, if a ship is one thousand feet up it can glide forward five times that, or five thousand feet. Some larger ships will glide still farther, while small, single-seated ships may not glide so far. It sometimes becomes necessary to avail oneself of all possible gliding distance in order to reach a suitable landing spot when the motor has cut out. A steeper glide is usually made for landing purposes and the correct angle should be taught first. The difference between the correct glide and the stalling angle should be thoroughly understood before the slow, flat glide and dive are introduced to the pupil. In connection with gliding the pupil should be required to stall the machine frequently, both with and without engine on, and thereby get an approximate idea of the air room necessary underneath to recover. After a pupil has demonstrated the steadiness of his nerves, stalling should be practiced close to the ground as well as at an altitude because he is better able to visualize the space needed if close to the ground.

The future expertness and safety of a pupil will depend a great deal on the extent to which he instinctively maintains flying speed even under the adverse circumstances and distractions of a difficult forced landing. During the course of instruction in the air on dual control the instructor should frequently change the gliding angle of the pupil, both increase and decrease it, and see whether the pupil can correct it again promptly and easily. He should be familiarized with the sound of the wind through the wires or other bracing and its indication of speed so that in misty or heavy weather when the horizon is obscured he can still maintain the proper balance and glide. When, and not until, the pupil can turn and glide properly, practice in landing should be commenced.

Landing.—While turns and glides are practiced in almost any weather, it is better to start landing instruction at least in moderately calm weather. The fundamental principle underlying successful landings is the ability to judge distance both of the height

above ground and distance ahead. The first thing for the pupil to learn is to judge his distance above ground in order to know the exact instant to flatten the ship out for a landing. Practice in judging distance must not be overlooked, however, because it is just as important to know how far back to start a glide for the altitude from which it is started.

A very important matter of instruction is the proper way to approach a field for landing. Altitude should not be lost over the middle of an airport but to leeward or down wind, clear of the field. It should be done by gliding back and forth at right angles to the direction in which it is intended to land, always making the turns toward the airdrome and not away from it, that is, make a right hand turn at one end and a left hand turn at the other end. This is in order to be always headed for the landing area in case of difficulty. The final turn toward the landing spot should be made when just the proper altitude remains to insure clearing any obstacles and a normal glide will carry the ship in.

Experienced pilots do not follow this procedure as a rule because it doesn't provide sufficient thrill for their liking. They would rather approach the field along the down wind border and at right angles to the direction of final landing, side-slipping steeply, thus loosing altitude quickly with comparatively little forward movement. Another way is to head into the wind but seesaw the tail back and forth, which results in slight skids first one way then the other and a consequent loss of speed and altitude.

These practices should never be allowed at a field where instruction goes on as it is liable to influence beginners to attempt the same maneuver which might result in disaster.

The usual airport landing field is of large area and for this reason pupils do not have to exercise their distance judgment to any great extent with the result that it is neglected. Then when it becomes necessary to land in a small field they experience difficulties. For this reason it is of the utmost importance that, after the first few landings, the pupil be required to bring the machine to a full stop within a certain predetermined and marked-out comparatively small area. This practice should be continued through the entire course of training in order to make it second nature for

the pilot to bring his machine to rest at any predetermined spot on any airdrome, large or small.

Since the pupil has already been instructed how to glide and turn accurately, it is not necessary to insist on long circuits of the field and long straight glides between landings. It is better to incorporate practice and instruction on short turns and steep banks, easy side slips and low flying at the same time. Circling the field should be done alternately to the right and to the left in order to overcome any tendency to turn only in one direction. Landings with a "dead stick," when the motor is completely shut off and the propeller stationary, should be practiced in order to familiarize the pupil with the different feel a ship has under these conditions. He may have to make landings under these circumstances at times, and a knowledge of how to accomplish this task is most essential.

Pupils should be taught to treat all landings in all weathers as forced, and never be allowed to drag themselves into the landing area with the help of the engine. This is the only way to teach the proper gliding angle and judgment of distance. The pilot who fails to treat each landing as forced is the one to crash when the engine fails and he has to make a forced landing.

Taxiing.—It should be explained to pupils and shown that the torque of the engine and gusts of wind tend to make some machines difficult to taxi on the ground. Due to the air speed of the machine being so slow, and hence the effect of the controls so slight, it is necessary to correct any tendency of the machine to swing by over application of the rudder. It is often necessary to provide an air blast on the rudder by opening up the engine momentarily. The tendency to swing must be checked immediately; anticipation of the tendency is still better, because once started, a swing is often difficult to check without coming to a complete stop.

In taxiing heavy machines, two-seaters and larger, the stick should be kept well forward, the object being to lift the tail from the ground as much as possible, or at least relieve the tail skid of some of the weight. With lightweight single-seaters the stick should be kept well back providing a braking effect through the tail skid, and care should be exercised while taxiing this type of ship to keep it headed into the wind as much as possible. They are light and touchy, very liable to be blown over if carelessly handled.

General Hints.—Flights not exceeding one-half hour at a time are sufficient at first, and before going up, the pupil should be given a short explanation of the maneuver to be practiced, followed by a criticism after landing. Sufficient time should elapse between instruction flights to allow the student to think over what he has learned and he should be encouraged to discuss his experiences and ask any questions with both his instructor and other pilots.

In order to develop a really accurate flying sense in the pupil he should not be encouraged, rather discouraged, in the use of the instruments of the plane. It is better that he be able to recognize the proper tone of the engine, the sound of wind when proper flying speed is being maintained, and feel a sense of balance when the ship is in trim rather than continually having to consult the instruments to tell him.

After having received from six to ten hours' air instruction, spread over a period of several days, the pupil should be able to accomplish the following maneuvers with confidence and moderate accuracy; holding a steep bank on sharp turns; simple stalls and side slips, recovering from them without throwing the ship into a tail spin; safe turns close to the ground; S turns or figure eights; and fairly accurate, soft landings. If the student can perform these well, he is ready for his first solo flight alone in the ship.

First Solo.—The first solo period should not last more than a few hours and be for the purpose of perfecting landings and turns, at the same time becoming accustomed to being alone. From the time solo flights are commenced until the student has finished his training, he should never be allowed to go up for the purpose of doing nothing except straight flying. Whenever he flies he should be practicing something; steep banks, figure eights; stalls; landings; or throwing the machine about. If he does not seem to want to do this, his confidence is not what it should be, and more dual should be given. Before each solo flight the instructor should outline some definite job to do. The main object of being in the air is to learn to fly and common straight flying around the country teaches nothing.

The instructor, from the ground, should watch his pupil's actions while solo flying, and any faults which show up, such as slipping on turns, bad landings, too flat a turn, etc., should be checked at once, not only by verbal instruction, but by further dual control.

Second Dual.—After several solo flights in which the pupil has begun to show confidence in flying alone and also that he has grasped the lessons already taught him, he should be taken in hand for a second course of dual instruction. This should not require over a couple of hours' air time and should be sandwiched in with solo flights. He should be given an air examination on what was taught in the first dual, and any errors that developed should be corrected before going on with further instruction. As much instruction during the second dual period as possible should be done in bumpy weather, so that when finished, the pupil will have lost all fear of rough-weather flying. Steep banks in bumps, climbing on the turns, spirals, side slips, cross-wind work and forced landings should be included.

An instinctive knowledge of flying speed and the stalling angle is most essential in order to turn and at the same time climb. Climbing on a turn should not be attempted with more than a forty-five degree bank, and then with the motor full on. If the plane starts to stall the nose should be dropped to allow it to pick up flying speed again.

Taking Off and Landing Across Wind.—In case of a forced landing it may often be necessary to land and take off across the wind, especially in small fields where there is not enough room to do otherwise. In a high wind it may be possible to land into it, due to the greater retarding effect—judgment of which course to pursue will come with experience.

If properly done with full knowledge of stalling and slipping, landing across the wind is not difficult. Under these conditions the ship will drift over the ground in the direction of the wind. In order to counteract this drift it is necessary to side-slip into the wind, the amount depending upon the force of the wind. The slip should be maintained until the moment that the lower wheel touches the ground and continued for as long as possible after the machine touches the ground. The flattening out is done quite independently of the slip by pulling the stick back, at the same time maintaining the bank. It is not good policy to attempt a three-point landing under these conditions, but better to keep the tail up for the purpose of maintaining lateral control as long as possible, and favor the one wheel carrying the full load.

In taking off across the wind push the stick forward to get the tail up as quickly as possible, at the same time banking slightly into the wind. It will be necessary to apply top rudder to maintain direction. Do not waste any time in leaving the ground, but get off as soon as possible, keeping the bank. Level off fore-and-aft to gain flying speed, then turn into the wind and climb.

These maneuvers should be practiced with the wind on the left as well as on the right. As this work comes under the head of forced landings, it is well to practice getting into small fields of various characteristics, landing both into the wind and across the wind. It is well to let the pupil form an opinion of the type of field he picks from a considerable altitude, then drop down and see how near his judgment was right. In this way practice will be gained in recognizing the appearance of different kinds from high altitudes, which is very often quite different from the actuality.

Final Dual.—Final dual instruction should be done for the purpose of teaching the correct way to execute the more advanced maneuvers and acrobatics. This should not be started, however, before the pupil has demonstrated his ability to carry out all that has gone before. It is a very common sight to see a pupil side-slipping and spinning close to the ground, showing a dangerous ignorance of how to recover smoothly.

A careful explanation of the maneuver, with possible practice in a dummy cockpit on the ground, should be given by the instructor before attempting it in the air. If, while in the air, the pupil gets into any difficulty, the instructor should not come to his rescue at once but allow the student to exhaust his own methods of recovery first. An occasional, quietly spoken direction under these circumstances will often do more than jerking the controls away and leveling out. The pupil will not have learned anything if the instructor insists on getting him out of difficulty.

The final solo should be for the purpose of practice in everything the pupil has learned and can only be governed by the allotment of time given him. Under the instructor's watchful eye, the pupil should be required to execute accurately every maneuver he has been taught before turning him loose as a first-class finished pilot.

CHAPTER XXI

AIR COMMERCE REGULATIONS *

(See Index of Air Commerce Regulations at end of this Chapter)

FROM the following regulations you will realize that flying is being made safe. These rules and regulations have been copied exactly as they appear in the book of regulations issued by the Department of Commerce, Aëronautics Branch, and contain the law enacted to eliminate haphazard, irresponsible flying and the operation of unsafe aircraft. There is nothing in the law that would hamper a capable air man or keep him from operating an airworthy airplane.

In regard to the airmen themselves, it is necessary that they be competent to perform the work they claim they are capable of. When this is proved they receive a statement to that effect in the form of a license which, when shown to a prospective employer, tells him more than the applicant could himself.

I would suggest that, if you intend to take flying instruction with a view of becoming a commercial pilot, you first see if you can pass the physical examination required. If you can't there is no use in spending time and money in taking the training. Examination may disclose something that you were not aware of and save you from having an accident or at least from getting ahead as you should if you entered some other branch of the work for which you are better fitted physically.

The money earned by qualified airmen is better than in any other like capacity in another industry. Air mail pilots receive from five to twelve thousand dollars a year. One large commercial company with a mail contract guarantees their pilots twenty-two hundred dollars a year and additional flying time to make five thousand dollars a year. Mail routes pay the pilots by the mile, different

* Air commerce regulations covering practically the same ground are now in force or are being adopted in practically all the countries of the world.

rates being paid for different routes, depending upon the difficulty of navigation and hazard. Night flying pays from two to three cents a mile more than does day flying. The result is that a pilot flying a dangerous night route receives about fifteen cents a mile, sometimes more, and it doesn't take long to cover a mile in those air mail wind splitters.

The routes are laid out in divisions, similar to railroad practice, and a pilot is very seldom required to be in the air for more than four hours at a time. Then he is due at a division point, and the mail is transferred to another pilot and plane who carries it over the next division. The relieved pilot rests until the next day and then flies the mail back to his starting field. On short routes one pilot may make a round trip with a short rest period between.

If you have read this book through, you should have learned enough about aviation to decide whether or not you might like it. If you do and desire deeper information on any of the different subjects, books are published devoted to one subject alone, going into much greater detail than I have been able to give here. Books are published dealing only with navigation, aërodynamics, engine design, weather forecasting, airplane design and construction, with load factors worked out for different kinds of work, and others.

The examinations given by the Secretary of Commerce are not too difficult, but are made to find out if the applicant has any competent idea about aviation before certifying to the fact. If you study this book as it should be studied, you should be able to pass any of the examinations, with the possible exception of the transport pilot's, and it would be impossible to pass this anyway without the required solo flying. While gaining this time it is possible to study the required subjects in more detail and prepare to pass the examination in due time.

The following are the Air Regulations issued and enforced by the Aëronautics Branch of the United States Department of Commerce, effective on and after December 31, 1926.

LICENSING OF AIRCRAFT

Section 1—*Licensing Law*

"Air commerce" means transportation in whole or in part by aircraft of persons or property for hire, navigation of aircraft in

furtherance of business, or navigation of aircraft from one place to another for operation in the conduct of a business. [Sec. 1, *Air Commerce Act*]

"Interstate or foreign air commerce" means air commerce between any State, Territory or possession, or the District of Columbia and any place outside thereof; or between points within the same State, Territory or possession, or the District of Columbia, but through the air space over any such place outside thereof, or wholly within the air space over any Territory or possession or the District of Columbia. [Sec. 1]

The Secretary of Commerce shall, by regulation . . . provide for the granting of registration to aircraft eligible for registration, if the owner requests such registration . . . [Sec. 3 (a)]

It shall be unlawful to navigate any aircraft in interstate or foreign air commerce unless such aircraft is registered as an aircraft of the United States. [Sec. 11 (a) (2)]; to navigate any aircraft registered as an aircraft of the United States . . . without an aircraft certificate, or in violation of the terms of any such certificate. [Sec. 11 (a) (3)]

Any person who (1) violates any provision or subdivision (a) of this section . . . shall be subject to a civil penalty of $500.00 . . . . [Sec. 11 (b)]

Aircraft means "any contrivance now known or hereafter invented, used or designed for navigation of or flight in the air, except a parachute or other contrivance designed for such navigation but used primarily as safety equipment." [Sec. 9 (c)]

Aircraft of the United States means "any aircraft registered" under the *Air Commerce Act*. [Sec. 9 (f)]

Section 2—*Application of the Law*

Aircraft must be licensed before engaging in:

(A) Carrying persons or property for hire or reward, the United States Mails—

1. Between two or more States, or to or from foreign countries; as from Chicago to Dallas, Texas, or from New York to Portland, Maine, to Montreal, Canada.
2. Between two points in one State if a part of the flight is over another State, as from Buffalo, New York, to New York City by way of Susquehanna, Pennsylvania, or from Buffalo then over any part of Pennsylvania and then back to Buffalo.
3. Between two points in one State if a part of a through

carriage between points in different States, or countries, as from Los Angeles to San Francisco, California, as a part of the carriage between Los Angeles and Seattle, Washington, or from San Antonio, Texas, to Laredo, Texas, as a part of the carriage between San Antonio and Monterey, Mexico.

4. Within the air space over the District of Columbia or any Territory or possession of the United States.

(B) Flying between points in different States, the District of Columbia, or Territories or possessions of the United States, or to or from any foreign country, for the operation in the conduct of a business, as where the aircraft is used in a business in one State, Territory or possession of the United States or the District of Columbia and is flown to another State, Territory or possession for use in the business in that State, Territory or possession. Applied to concrete facts, it includes the aircraft which is used in State "A" for exhibition purposes, or the carriage there of persons or property for hire or reward, and is flown to State "B" for exhibition purposes or for the carriage there of persons or property for hire or reward. A pleasure or noncommercial aircraft need not be licensed, although engaged in flying between States. Such aircraft, however, may be licensed upon the request of the owner in which event it must observe all the requirements of licensed aircraft. Whether licensed or not all aircraft must display the assigned identification mark. (This compares with the license number on motor vehicles.)

Section 3—*Aircraft Belonging to the United States*

Aircraft belonging to the United States will be licensed by the Secretary of Commerce if the operating agency so requests.

Section 4—*Aircraft Belonging to States, Etc.*

Aircraft belonging to States, Territories, possessions of the United States, or to political subdivisions, will be licensed by the Secretary of Commerce and rated as to airworthiness in the same manner as other craft if request for licensing is made and such aircraft are used exclusively in government service.

Section 5—*Foreign Aircraft*

Where civil aircraft of the United States are permitted to fly in or over a foreign country without registration and rating and licensing of their airmen, the aircraft of such foreign country, not

a part of its armed forces, and the airmen serving in connection therewith (military planes and airmen), may operate without a license in the Territory over which the United States has jurisdiction. Such foreign aircraft shall not engage in interstate or intrastate air commerce.

Section 6—*Prerequisite to License*

An aircraft will be licensed after it is registered and found airworthy.

Section 7—*Registration, Meaning of*

Registration means entry of licensed aircraft in an official license registry of the Secretary of Commerce as an aircraft of the United States. Unlicensed aircraft, though entered of record for purposes of identification as required by law, are not registered aircraft within the meaning of these regulations.

Section 8—*Requisite of Registry*

An aircraft to be entitled to registration must be owned by:—

(A) A citizen of the United States and not registered under the laws of any foreign country; or

(B) A partnership of which each member is a citizen of the United States; or

(C) A corporation organized under the laws of the United States, a State, a Territory, or possession of the United States, and of which the president and at least two-thirds of the directors or managing officers are citizens of the United States, and of which at least 51 percent of the voting interest in the corporation is controlled by citizens of the United States; or

(D) The government of the United States, a State, Territory or possession, or a political subdivision thereof, and used exclusively in the governmental service.

Section 9—*Airworthiness, Law of*

The Secretary of Commerce shall by regulation . . . provide for the rating of aircraft of the United States as to their airworthiness . . . The Secretary may from time to time rerate aircraft as to their airworthiness upon the basis of information obtained under this subdivision. [Sec. 3 (b)]

It shall be unlawful to navigate any aircraft registered as an aircraft of the United States without an aircraft certificate or in violation of the terms of any such certificate. [Sec. 11 (A) (3)]

Any person who violates any provision or subdivision (A) of this

section . . . shall be subject to a civil penalty of $500.00. [Sec. 11 (b)]

Section 10—*Airworthiness, Meaning of*

Airworthy means a condition meeting the minimum requirements of this chapter.

Section 11—*Airworthiness Factors*

In determining airworthiness, consideration will be given to the following:

(A) The structural strength of wings, ailerons, tail surfaces, fuselage, including engine mount, and landing gear.
(B) Cockpit, cabin, and control arrangements.
(C) Power plant and power plant installation.
(D) Equipment and instruments.
(E) Propellers.
(F) Fittings.
(G) Materials and workmanship.
(H) Flying characteristics and qualities.

Section 12—*Structural Strength Requirements for Airworthiness*

(A) To determine structural strength requirements airplanes shall be classified according to gross weight in pounds, as follows:
 Class 1. Up to 2,500 lbs.
 Class 2. Over 2,500 to 4,500 lbs.
 Class 3. Over 4,500 to 7,500 lbs.
 Class 4. Over 7,500 to 13,500 lbs.
 Class 5. Over 13,500 lbs.
(B) Wing-truss analyses and load factors.
(C) Aileron and tail surface strengths.
(D) Control system strength.
(E) Fuselage strength.
(F) Strength of landing gear.
(G) Strength of fittings.

Section 13—*Construction of Cockpit, Cabins and Controls*

(A) The cockpit must be constructed to afford:
 1. Suitable ventilation.
 2. Adequate vision to pilot under normal flying requirements.
 3. Reasonable protection to pilot and passengers against possible propeller breakage.
(B) Closed cabins on airplanes carrying passengers for hire or reward must have not less than two exits affording maximum ease of operation.

(C) Dual control on airplanes carrying passengers for hire or reward shall be so constructed or arranged as to prevent passengers from interfering with the course of flight of the airplane.

Section 14—*Power Plant Requirements*

(A) The power plant must be equipped with:

1. Fire wall, or equivalent protection, insulating engine section from other parts of the airplane in case of fire, and provided with glands or gaskets when pierced by pipes or wires.
2. Carburetor air intakes opening outside the fuselage and must be suitably drained.
3. Throttle control and ignition switches on multi-engined airplanes arranged to permit separate and simultaneous control.
4. Suitable ventilation for engine compartments.
5. No air pressure gasoline feed system, except with special approval of the Secretary of Commerce.
6. For airplanes carrying passengers for hire or reward adequate reserve gasoline supply tank or satisfactory and reliable apparatus for indicating to the pilot a depletion of the gasoline supply.

(B) 1. An engine of new type and design must be bench-tested for not less than fifty hours, of which at least five hours must be at full throttle. A log (detail record) of such test must be filed with the Secretary of Commerce.

2. A newly constructed engine of a type and design which has been tested in accordance with the provisions of subparagraph (1) hereof must not be installed in an airplane until bench-tested for at least two hours, during at least one-half hour of which the engine must be run at full throttle.
3. An engine which has been in storage for more than one year must not be installed in an airplane until it has been reconditioned in accordance with accepted safety practices.
4. A reconditioned engine must be run for at least twenty minutes at full throttle before it shall be used in propelling registered aircraft carrying persons or property for hire or reward.

Section 15—*Equipment and Instrument Requirements*

The equipment and instruments required, which must be serviceable and in operating condition, are:

(A) Equipment:

1. Fire-extinguishing equipment of design approved by the Secretary of Commerce. Cabin airplanes carrying passengers for hire or reward must be equipped with at least one portable extinguisher accessible to the passengers.
2. First-aid kits on airplanes carrying passengers for hire or reward.
3. Safety belts or equivalent apparatus for pilots and passengers in open-cockpit airplanes carrying passengers for hire or reward.

(B) Instruments:

1. Tachometer for each engine.
2. Oil-pressure gauge where oil-pressure systems are used.
3. Water thermometer for water-cooled engines and oil thermometer for air-cooled engines.
4. Altimeter.

Section 16—*Propellers*

(A) Propellers must have:

1. Ground clearance of at least six inches when plane is in horizontal position.
2. At least three inches of clearance, on multi-engined land and seaplanes, between tips of the outboard propellers and the fuselage or any of the plane structure.

(B) Propellers must be balanced and wooden propellers must be without open glued joints, and

(C) Propellers must be of a type design approved by the Secretary of Commerce.

Section 17—*Materials and Workmanship*

The materials used in airplanes and engines must be of the accepted standards and clearly adapted to the purpose for which used, and the workmanship must be good.

Section 18—*Seaworthiness of Seaplanes*

Seaplanes, including amphibians, must also be seaworthy.

Section 19—*Formulae for Test Flight*

(A) Except as provided in subparagraph (B), all airplanes other than seaplanes, whether constructed before or after these regulations take effect, must meet the calculations of both of the following formulae:

1. $$\frac{\text{Gross weight}}{\text{Horsepower}} \times \frac{\text{Gross weight}}{\text{Wing area}} = 200 \text{ or less.}$$

2. $$\frac{\text{Gross weight}}{\text{Horsepower}} + \frac{\text{Gross weight}}{\text{Wing area}} = 30 \text{ or less.}$$

(B) If either of the calculations is in excess of the figures stated above, the airplane must pass the following flight tests with full load:

1. Take-off within 1,000 feet.
2. Climb at least 200 feet the first minute after take-off.
3. Land, coming to a full stop without external aid, within 1000 feet from point where wheels first touched the landing area.

Tests are to be calculated upon the basis of air of a specific weight of 0.07635 and of wind velocity not exceeding ten miles an hour.

Section 20—*Manufacturer's Number and Date*

The date of manufacture or the date of remodeling and the name of manufacturer or remodeler, together with the serial or other number, must be permanently affixed to a visible and protected part of the licensed aircraft in order that it may be distinguished from other aircraft.

Section 21—*Manufacturer's Approved Type Certificates for Airplanes*

(A) Application—A manufacturer of airplanes in quantities and of an exact similarity of type, structure, materials, assembly and workmanship may, at the option of the manufacturer, file with the Secretary of Commerce an application for an approved type certificate.

(B) *Accompanying information*—The application must be accompanied, under oath, by:

1. Three view drawing of the airplane with main dimensions, aërodynamical and other characteristics, accompanied by a balance diagram for varying conditions of load to be employed.
2. Description of power plant and power plant installation with illustrative diagrams.
3. Description of wings, fuselage, including engine mount, landing gear and tail surfaces, materials employed, and drawings or dimensioned sketches of main structural members.

4. Stress analysis, with signature of responsible engineer.

The information furnished by manufacturer under subparagraphs (A) and (B) will treated as confidential.

(C) *Inspection and tests of specimen.* If the Secretary of Commerce approves the submitted design and the aircraft meets the requirements of Section 19, it will be inspected for exact similarity with the submitted design and specifications. Upon passing such inspection the airplane must undergo the flight tests prescribed in Section 26. If such tests are passed the Secretary of Commerce will issue to the manufacturer an approved type certificate.

(D) *Duration and conditions of approved type certificates.* The approved type certificate will be issued upon the conditions that each quarter the manufacturer will file its affidavit with the Secretary of Commerce showing the number of airplanes constructed under the approved type certificate during the quarter, with a statement that no airplane is being constructed under the approved type certificate deviating from the terms thereof.

(E) *Changes.* Changes in airplanes constructed under an approved type certificate are permissible, with the approval of the Secretary of Commerce.

(F) *Manufacturer's affidavit.* Upon the sale by the manufacturer of airplanes of an exact similarity . . . with the specimen for which the approved type certificate is issued, the manufacturer may deliver to the purchaser a manufacturer's affidavit, a copy of which is shown in the form of registry of the Secretary of Commerce.

Section 22—*Application for Aircraft License*

Before an aircraft license will be issued, the owner must file, under oath, with the Secretary of Commerce, an application for the license upon a blank prepared in conformity to the form of the application in the form of registry of the Secretary of Commerce. Copies of such application will be forwarded upon request.

Section 23—*Licensing and Expediting the Licensing of Approved Type Airplanes*

(A) For the purpose of hastening the licensing of airplanes constructed under approved type certificates and in the original possession of the manufacturer or dealer, the following provisions may be invoked, at the option of the manufacturer or dealer:

The manufacturer or dealer may present the manufacturer's affidavit showing that the aircraft is exactly similar to the specimen of the approved type and have the airplane flight tested. If the flight tests prescribed in Section 26 (A) are passed and the aircraft inspector finds that the airplane is exactly similar to the specimen, a flight certificate will be issued for such airplane, good for ninety days after date and renewable for ninety-day periods upon findings of the Secretary of Commerce that the airplane is in substantially the same condition as when the original certificate was issued. The manufacturer's affidavit and the flight certificate may be delivered to any purchaser and will be given such effect as is provided therefor in paragraph (B) of this section.

(B) An airplane constructed under an approved type certificate and in the possession of and owned by an eligible owner of aircraft of the United States, will be licensed as follows:

1. If the application is accompanied by the manufacturer's affidavit, the airplane will be inspected for similarity to the specimen and will be given the flight tests prescribed in Section 26 (A). If such inspection and tests are passed and the airplane is found to be equipped as required by these regulations it will be licensed.
2. If the application is accompanied by both the manufacturer's affidavit and a valid flight certificate it will be licensed if found to be equipped as required by these regulations.
3. If the application is not accompanied by the manufacturer's affidavit and the flight certificate, it will be licensed under the provisions of Section 24 hereof.

Section 24—*Licensing of Airplanes not Constructed Under Approved Type Certificates*

(A) For an airplane constructed after October 1st, 1927, and not manufactured under approved type certificate, the application for the license must be accompanied by the information specified in Section 21 (B).

(B) *Tests:*

1. For an airplane constructed after October 1st, 1927, in conformity to the airworthy requirements of these regulations and which passes the flight tests specified in Section

26, an aircraft license will be issued by the Secretary of Commerce.

2. For airplanes constructed prior to October 1st, 1927, and found by the Secretary of Commerce to be of proper design, assembly and workmanship, and of suitable materials and equipped in accordance with these regulations, aircraft licenses will be issued after such airplanes have passed the flight tests specified in Section 26 (B).

Section 25—*Licensing of Special Classes of Airplanes*

Racing and experimental airplanes and airplanes of unusual design will be granted special aircraft licenses and shall be operated only in accordance with the conditions specified in such licenses.

Section 26—*Flight Tests*

The flight tests referred to in this chapter are of two kinds:

(A) General flight, which is one-half hour flying test with full load to determine stability; and

(B) General maneuverability, which includes, among other things, a flight with full load around two pylons or buoys 1,500 feet apart, making five successive figure eights at eight hundred feet altitude without varying more than 200 feet in height and in a radius not to exceed the following:

1. Five hundred feet for airplanes of full load not in excess of 4,500 pounds;
2. Seven hundred and fifty feet for airplanes of full load over 4,500 pounds and not in excess of 13,500 pounds; and
3. One thousand feet for all other airplanes.

The applicant must provide the person to make the flight tests, but the inspector will pilot the airplane during such parts of the tests as shall be deemed necessary.

Section 27—*Places for Airworthiness Tests*

The Secretary of Commerce will fix the time and place for all inspections and tests for airworthiness.

Section 28—*Licenses—Contents*

Aircraft licenses will be issued for a period of one year, and will identify the airplane, specify the authorized type of engine, and state the authorized gross weight, and will be granted subject to compliance with these regulations.

Section 29—*Sale of Licensed Aircraft*

Upon the sale or transfer of title of licensed aircraft the licensed owner must report to the Secretary of Commerce the date and

place of sale or transfer and the name and residence of the vendee (purchaser). If the sale is to an ineligible owner of aircraft of the United States, the aircraft license immediately terminates. If to an eligible owner, the license terminates thirty days after such sale or transfer, during which time the vendee may file a "purchaser's renewable" application and have the aircraft relicensed in his name for the unexpired term of the existing license. Between the sale and the said relicensing the aircraft will be considered as licensed in the name of the purchaser if the purchaser's renewable application is filed within the time provided herein. If the application for the relicensing is not made within the time aforesaid, the license of the aircraft will be governed by the regulations applying to the original license.

Section 30—*Relicensing of Aircraft*

Upon the expiration of the term of an existing aircraft license the aircraft will be relicensed for additional periods of one year upon the application of the owner for relicensing and the finding of the Secretary of Commerce that the aircraft is airworthy and is owned by an eligible owner.

Section 31—*Cancelling Licenses Upon Request*

Upon the request of the licensed owner the aircraft license will be cancelled by the Secretary of Commerce.

Section 32—*Revocation and Suspension of Licenses—Law*

The Secretary of Commerce shall by regulation . . . provide for the . . . suspension and revocation of registration (and) aircraft certificates. [Sec. 3(f)]

Section 33—*Ground for Revocation or Suspension*

Aircraft licenses will be suspended or revoked for:—

(A) Violating the Air Commerce Act or any of these regulations.

(B) Failure to make proper and seasonable reports.

(C) Making false statement in application or information accompanying the application for the license, or in any report required under these regulations.

(D) Equipping the airplane with a type of engine not specified in the license or approved by the Secretary of Commerce.

(E) Remodeling the engine and using it to propel licensed aircraft without the aircraft having been first rerated as airworthy by the Secretary of Commerce.

(F) Remodeling the airplane structure and flying the airplane

without having it rerated as airworthy by the Secretary of Commerce.

(G) Operating the airplane in excess of the authorized gross load specified in the license.

Section 34—*Display and Surrender of License*

The aircraft license must be carried in the craft whenever it is in service and must be conspicuously posted where it may be readily seen by passengers or inspectors. Whenever the craft is found to be unairworthy the license must be removed from the craft, and when the license is suspended or revoked, or when it is no longer in force, it shall be surrendered to the Secretary of Commerce. The license must be presented for inspection upon the demand of any passenger or of any authorized official or employee of the Department of Commerce.

Section 35—*Licensing of Airships and Balloons*

Until otherwise provided by regulations, the licensing of airships and balloons shall be in accordance with special orders of the Secretary of Commerce.

Section 36—*Meaning of Airplane*

Except as otherwise specifically shown, the word "airplane" as used in these regulations includes seaplanes.

Section 37—*Marking of Aircraft—Law of*

The Secretary of Commerce shall by regulation . . . establish air traffic rules for the . . . identification of aircraft. . . . [Sec. 3 (e)]

Section 38—*Identification Marks for Government and Special Classes of Aircraft*

(A) For aircraft belonging to the government of the United States identification marks or symbols will be assigned in accordance with arrangements to be made with the affected departments.

(B) Licensed airplanes engaged in racing or experimental work or specially licensed for other purposes, will be assigned special identification marks or symbols.

Section 39—*Identification Marks for Licensed Aircraft*

A licensed aircraft shall bear an identification mark consisting of the license number of the aircraft preceded by:

The Roman capital letter "S" (meaning "State") for aircraft used solely for government purposes and belonging to States, Territories, possessions or municipalities; and

The Roman capital letter "C," Fig. 175, for all other licensed air-

craft. Aircraft not licensed, but for which applications have been filed with the Secretary of Commerce, will be assigned only a temporary number pending the issuance of license.

The letter "N" must precede the identification mark on licensed aircraft engaged in *foreign* air commerce and at the option of the owner may precede it on other licensed aircraft. The identification mark will be assigned to *licensed* aircraft when the aircraft license is issued and a separate application therefore is not required.

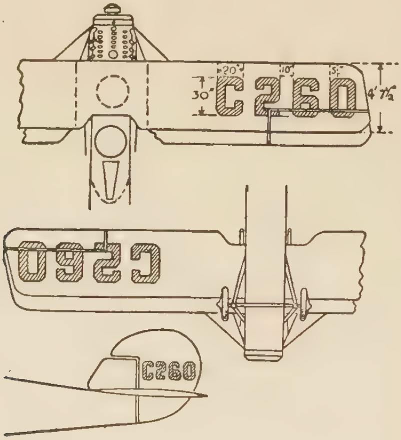

Fig. 175.—License marks of plane.

Section 40—*Identification Marks for Unlicensed Aircraft*

(A) Except as otherwise provided in this section, unlicensed aircraft must display, when in flight, an identification mark assigned by the Secretary of Commerce. The mark will be assigned upon the application of the aircraft owner and must be permanently affixed to the aircraft. It will consist of a number only and the letter "N" must not be made a part of it, nor shall any other letter, design, symbol or description be added to it. The mark may be used by any purchaser of such unlicensed aircraft upon his application therefor, if the application is filed with the Secretary of Commerce within twenty days of the delivery of the aircraft to the said purchaser and is accompanied by the bill of sale or a certified copy of it.

(B) A ferrying mark will be assigned to persons whom the Secretary of Commerce, upon application, finds are manufacturers of or dealers in aircraft. The mark shall be used only on unlicensed aircraft held for sale by the manufacturer or dealer, except that a purchaser thereof may use the mark for a period of not more than twenty days after the aircraft is delivered to him. A manufacturer's ferrying mark shall not be used by a dealer after the aircraft has been delivered to the dealer. The ferrying mark must be temporarily affixed to the aircraft and shall be kept clean and legible. An aircraft displaying a ferrying mark shall not carry persons or property for hire or reward.

Section 41—*Places and Dimensions of Marks*

Except as may be authorized under Sections 40 and 42, identification marks shall be located as follows:

(A) On airplanes—(see Fig. 175)—on the lower surface of the lower left wing and on the upper surface of the upper right wing, the top of the letters or figures to be toward the leading edge, the height to be at least four-fifths of the mean chord, provided, however, that in the event four-fifths of the mean chord is more than thirty inches, the height of the letters and figures need not be more but shall not be less than thirty inches. If the lower left plane is less than one-half of the span of the upper left plane, the letters or figures thus described shall be on the under surface of the upper left plane, as far to the left as possible. In the case of a monoplane the mark shall be displayed on the lower surface of the left wing and the upper surface of the right wing in the manner thus described. The marks shall also appear on both sides of the rudder, of size as large as the surface will permit, leaving a margin of at least two inches.

(B) On airships . . .

(C) On balloons . . .

Section 42—*Other Symbols and Marks*

Except with the approval of the Secretary of Commerce, no design, mark, character, symbol, or description shall be placed upon aircraft if said design, etc., modifies, subtracts, adds to, or confuses the assigned mark or impairs or destroys its visibility.

Section 43—*Identification Plate*

The identification mark, with the name and residence of the owner,

will be inscribed upon a metal plate furnished by the Secretary of Commerce. It must be affixed to the fuselage in a prominent place, but this section shall not apply to public aircraft of the United States.

Section 44—*Continuous Duty as to Flying Condition*

After an aircraft is licensed and between the times that it is inspected for airworthiness by an inspector, the owner is charged with the continuous duty of maintaining the aircraft in a good and proper state of repair and flying condition. For violation of this duty or of the inspections required in the next succeeding section the aircraft license will suspended or revoked.

Section 45—*Daily and Periodic Inspection*

A licensed airplane shall be given a line inspection by the owner at least once within each twenty-four hours preceding flight, and the result thereof shall be entered in the log under the signature of the person making such inspection. The line inspection must be made to ascertain the working condition and the state of repair of the—

1. Open control wires, all control wires and pulleys open to inspection through apertures, and all hinges on control surfaces.
2. Landing gear, wheels, fittings and shock absorbers.
3. Fuselage parts open to visual inspection.
4. Main plane external bracing, including fittings and struts, external wires, cables, turnbuckles, and fabric or covering.
5. Control surface fabric or covering.
6. Engine exhaust manifolds and exhaust pipe extensions. The engine shall be given a warming up test, during which the proper functioning of the engine instruments shall be ascertained.
7. Carburetors and fuel feed lines open to visual inspection to insure proper functioning.
8. Cooling system and connections.
9. Cowling, to insure that cowlings are properly secured and safetied.
10. Propellers, as to condition.

(B) After each 100 hundred hours of flight, in addition to the line inspection, the airplane must be given a "periodic inspection" by the owner, and the result thereof must be entered in the log by the person making such inspection. This inspection must be made to ascertain the working condition and state of repair of the:

1. Engine installation.
2. Control systems throughout.
3. Propeller alignment.
4. Fuselage, including fittings, tail skid, and tail skid shock absorbers.

Section 46—*Government Inspections*

The inspector or other authorized officer of the Secretary of Commerce shall be permitted by the owner or operator to inspect the licensed aircraft at any time and place for the purpose of determining its flying condition and state of repair. For such purposes the owner or operator shall give to such inspector or officer free and uninterrupted access to the aircraft and the field or shelter where the craft is located.

Section 47—*Solo Flights with Passenger Planes*

In addition to the requirements of Section 14 (B), licensed airplanes with newly installed engines, old, new, or reconditioned, and airplanes upon which major repairs have been made to the plane structure, must be first test flown by a licensed pilot without passengers for hire or reward.

Section 48—*Carrying Passengers in Various Classes of Airplanes*

A licensed pilot must not carry passengers for hire or reward in an airplane of any one of the classes specified in Section 12 (A) unless he has piloted an airplane of that class for at least two hours within the last preceding ninety days, except where he makes practice flights in the airplane of such class for at least one-half hour and takes it off and lands it at least ten times. At least three of the landings must be to a full stop.

Section 49—*Seaplane Piloting*

A licensed pilot must not carry passengers for hire or reward in a seaplane unless he has piloted a seaplane for at least two hours within the last preceding ninety days, except where he makes practice flights in the seaplane for at least one-half hour and takes it off and lands it at least ten times. At least three of the landings must be to a full stop.

Section 50—*Pilot's Night Flying Qualifications*

A transport or limited commercial pilot who has not had at least one hour of night solo flying within the last preceding thirty days must not pilot an airplane with passengers for hire or reward between one-half hour after sunset and one-half hour before sunrise, except where he makes night solo flights for at least one-half hour, and takes off and lands at night at least ten times. At least three of such landings shall be to a full stop.

Section 51—*Carrying Passengers at Night*

Licensed aircraft when engaged in carrying passengers for hire any time between one-half hour after sunset and one-half hour before sunrise must be equipped with landing lights, navigation lights and a Very's pistol or approved equivalent of a Very's pistol.

Section 52—*Compass Requirements*

An airplane flying cross country one hundred or more miles and an airplane, including a seaplane, operating over large bodies of water beyond the sight of land, must be equipped with a compass.

Section 53—*Supplies and Equipment for Flights Over Water*

An airplane flying over large bodies of water must be provided with an adequate supply of food and potable water, and if engaged in carrying passengers for hire or reward must be equipped with a Very's pistol, or approved equivalent, and lights and life preservers or other flotation devices approved by the Secretary of Commerce.

Section 54—*Repairs After Accident Report*

After repairs have been made on licensed aircraft which has been seriously damaged the licensed owner shall make full report to the Secretary of Commerce of the kind and extent of repairs made to the craft.

Section 55—*Flying Seriously Damaged Airplanes*

A licensed airplane which is seriously damaged must not be flown with passengers for hire or reward until it has been fully repaired and its flying condition approved by an inspector.

Section 56—*Accident Reports*

Where serious injury to person or property is suffered or death results in operating licensed aircraft, the owner of such aircraft shall immediately report, by telegraph or telephone, to the Secretary of Commerce, the license number of the aircraft and the time and place of the accident. All accidents in the operation of licensed aircraft which result in injury to the aircraft shall be reported without delay on the form shown in the form registry.

Section 57—*Logs and Navigation Reports*

The owner or operator of every licensed aircraft shall keep a navigation and engine log book, and shall quarterly transmit to the Secretary of Commerce a navigation summary report, in duplicate, showing the number of hours and the approximate number of miles the aircraft has been flown during the quarter, the duration of the use of each engine, and the engine installation and repairs, and the plane structure and rigging changes and repairs.

Section 58—*Foreign Air Commerce*

Until otherwise provided, the laws of the United States and regulations made thereunder with respect to the entry and clearance of vessels engaged in foreign commerce are hereby made applicable to aircraft engaged in foreign air commerce.

LICENSING OF PILOTS AND MECHANICS

Section 59—*Pilots and Mechanics, Law of*

The Secretary of Commerce shall by regulation:

"Provide for the periodic examination and rating of airmen serving in connection with aircraft of the United States as to their qualifications for such service." [Sec. 3 (c)]

"The term 'airman' means any individual (including the person in command and any pilot, mechanic, or member of the crew) who engages in the navigation of aircraft while under way, and any individual who is in charge of the inspection, overhauling, or repairing of aircraft." [Sec. 9 (k)]

"It shall be unlawful . . . to serve as an airman in connection with any aircraft registered as an aircraft of the United States . . . without an airman's certificate or in violation of the terms of any such certificate." [Sec. 11 (a) (4)]

"Any person who violates any provision or subdivision (a) of this section . . . shall be subject to a civil penalty of $500.00." [Sec. 11 (b)]

Section 60—*Application of the Law*

For the purpose of this chapter, persons in command of licensed airplanes in flight will be classed as pilots, and persons repairing or adjusting licensed aircraft in flight and persons in charge of the ground inspection, overhauling, or repairing of licensed aircraft will be classed as mechanics. A workman or mechanic may engage in the repair or overhaul of licensed aircraft without being licensed if such repair or overhaul is in charge of a licensed mechanic.

Section 61—*Classification of Pilots and Mechanics*

Licensed pilots are classed as commercial or private pilots. Commercial pilots are licensed as transport, limited commercial, or industrial pilots. Private pilots are designated as private pilots (without other qualifications) or as student pilots. Mechanics are licensed as engine or airplane mechanics. A person may hold a plurality of licenses, such as both classes of mechanic's licenses or as a pilot's and mechanic's license. A transport pilot will not be issued other classes of pilot's licenses.

Section 62—*Privileges and Restrictions of Licensed Pilots*

Except as otherwise provided in these regulations, the privileges conferred and the restrictions imposed upon licensed pilots are as follows:

(A) Transport pilots may pilot any type of licensed aircraft but not unlicensed aircraft carrying persons or property for hire or reward. Transport pilots shall have all of the privileges of navigating aircraft conferred upon other classes of pilots.

(B) Limited commercial pilots shall have all of the privileges conferred and be subject to all of the restrictions imposed upon transport pilots, except they shall not pilot aircraft carrying persons for hire or reward outside of the areas mentioned in their licenses.

(C) Industrial pilots may pilot any type of licensed aircraft not carrying persons for hire or reward but shall not pilot an unlicensed aircraft carrying either persons or property for hire or reward.

(D) Private pilots, not designated as students, may pilot licensed airplanes not carrying persons or property for hire or reward. Private pilots designated as students are licensed only for the purpose of piloting licensed airplanes when receiving flying instructions and such student pilots shall not pilot licensed airplanes carrying persons or property for hire or reward or for any other purpose than receiving flying instructions nor within any other area than that specified in their licenses.

Section 63—*Applications for Pilots' and Mechanics' Licenses*

An application for a pilot's or mechanic's license must be filed, under oath, with the Secretary of Commerce upon blanks furnished for that purpose. An applicant for a pilot's license, including a student's pilot license, must appear for a physical examination before a physician designated by the Secretary of Commerce and pass such examination, unless he is exempt under these regulations. An applicant for a mechanic's license is not required to take a physical examination.

Section 64—*Character—Age and Citizenship Qualifications*

An applicant for a pilot's license must be of good moral character. The minimum age requirements are 16 years for private pilots, 18 years for industrial, limited commercial and transport pilots. A private pilot may be a citizen of any country. An industrial, limited commercial or transport pilot must be (1) a citizen of the United States, or (2) a citizen of a foreign country which grants

reciprocal commercial pilot privileges to citizens of the United States on equal terms and conditions with citizens of such foreign country, or (3) an alien who has filed his declaration of intention to become a citizen of the United States prior to December 31, 1927, and transmits a certified copy thereof to the Secretary of Commerce. He must diligently and successfully prosecute the naturalization proceeding under penalty of the revocation of his pilot's license and from time to time must keep the Secretary of Commerce advised of the status of such proceedings.

Section 65—*Flying Experience Requirements*

An applicant must have at least the following flying experience:

(A) *Transport Pilots.*—Two hundred hours of solo flying, of which at least five hours must have been within the last preceding sixty days prior to the filing of the application.

(B) *Limited Commercial Pilots.*—The same solo flying required of industrial pilots.

(C) *Industrial Pilots.*—Fifty hours of solo flying, of which at least five hours must have been within the last preceding sixty days prior to the filing of the application.

Section 66—*Pilots' Physical Qualifications*

The physical qualifications for pilots are as follows:

(A) *Private Pilots.*—Absence of organic disease or defect which would interfere with safe handling of an airplane under the conditions of private flying; visual acuity of at least 20/40 in each eye; less than 20/40 may be accepted if the pilot wears a correction in his goggles and has normal judgment of distance without correction; good judgment of distance; no diplopia in any position; normal visual fields and color vision; no organic disease of eye or internal ear.

(B) *Industrial Pilots.*—Absence of any organic disease or defect which would interfere with the safe handling of an airplane; visual acuity of not less than 20/30 in each eye, although in certain instances less than 20/30 may be accepted if the applicant wears a correction to 20/20 in his goggles and has good judgment of distance without correction; good judgment of distance; no diplopia in any field; normal visual fields and color vision; absence of organic disease of the eye, ear, nose, or throat.

(C) *Limited Commercial Pilots.*—The same physical qualifications prescribed for transport pilots.

(D) *Transport Pilots.*—Good past history; sound pulmonary,

cardiovascular, gastrointestinal, central nervous and genito-urinary systems; freedom from material structural defects or limitations; freedom from disease of the ductless glands; normal central, peripheral, and color vision, normal judgment of distance; only slight defects of ocular muscle balance; freedom from ocular disease; absence of obstructive or diseased conditions of the ear, nose and throat; no abnormalities of equilibrium that would interfere with flying.

(E) *Waivers.*—In the case of trained, experienced flyers, the Secretary of Commerce may grant waivers for physical defects designated as disqualifying by these regulations when in his opinion the experience of the pilot will compensate for the defect. A waiver once granted will hold indefinitely so long as the defect for which it was granted has not increased or unless canceled by the Secretary of Commerce.

Section 67—*Exemption from Prescribed Physical Examination*

An applicant for a pilot's license (or its renewal) will be exempt from the physical examination prescribed in these regulations upon filing with the Secretary of Commerce a certified copy of the examination for flying in the United States Army, Navy or Marine Corps made within six months of the date of filing his application for his pilot's license or its renewal, provided his physical qualifications as shown by such copy of the examination are not less than those required by these regulations for the class of license for which he applies.

Section 68—*Pilots' Examinations and Tests*

Unless exempt under these regulations, candidates must pass the following examinations and tests:

(A) *Transport Pilots.*—

1. Examination on air-traffic rules.
2. Practical and theoretical examination in elementary engine and plane mechanics and rigging and a theoretical examination in the fundamentals of meteorology and air navigation.
3. Practical flight test, as follows;

(a) Glide from 1,500 feet and land, in normal landing attitude, by wheels touching ground in front of and within 300 feet of a line designated by the examining officer. The engine shall idle from 1,500 feet, but

the throttle may be used to clear the engine down to the 500-foot height.

(b) Glide from 1,500 feet and land, in normal landing attitude, by wheels touching ground in front of and within 100 feet of a line designated by the examining officer. The free use of the engine is optional.

(c) Maneuver at 800 feet around two pylons or buoys 1,500 feet apart, making a series of five figure eight turns.

(d) Fly over a triangular or rectangular course at least 100 miles, landing at place of take-off within at least five hours. This flight shall also include two obligatory landings, not at point of departure, when craft must come to rest. The course will be designated and the candidate will be furnished with route information by the examining officer at time of departure and the examining officer will determine whether the course was correctly followed and whether the obligatory landings were satisfactory. Upon the presentation of satisfactory proof that the candidate has engaged in solo cross-country flights a distance of at least 100 miles within one year preceding the date of his application, the flight specified in this subsection will be omitted.

(e) Fly in emergency maneuvers, doing spirals, side slips, and recovering from stalls.

(B) *Limited Commercial Pilots.*—The same examinations and tests as are prescribed for transport pilots, except the cross-country flight and the examination on elementary meteorology and navigation.

(C) *Industrial Pilots.*—

1. Examination on the air-traffic rules.
2. The practical flight tests prescribed for transport pilots, except the distance for the cross-country flight shall be sixty miles.

(D) *Private Pilots.*—

1. Examination on the air traffic rules.
2. The practical flight test specified in subparagraph 3 (c) of Section 68 (A) and three satisfactory landings to a full stop. A private pilot, classed as a student, will be licensed without being required to pass the examination and tests prescribed in this paragraph.

Where seaplanes are used in the flight tests specified herein, the landing distance will be fixed by the Secretary of Commerce for each particular seaplane, according to its type and weight.

Section 69—*Pilots' Exemptions*

Candidates for pilots' licenses, meeting the requirements of Section 65 and who make claim for and produce satisfactory proof of their right to the following exemptions will not be required to pass any of the examinations specified in Section 68, except the examination on the air-traffic rules, and will be licensed as follows, if they possess the requisite physical qualifications:

(A) *As Transport or Limited Commercial Pilots.*—

1. Holders of airplane pilot ratings or certificates in the United States Army Air Corps, who are on active-duty status in the Regular Army Establishment; or,
2. Holders of naval aviators or naval aviation pilots certificates in the United States Navy or Marine Corps who are on active-duty status in the Regular Naval Establishment; or,
3. Persons actively engaged as pilots for not less than six months within the year preceding the date of application in carrying the United States mail for the Post Office Department of the United States or contractors thereof.

(B) *As Industrial Pilots.*—

1. Holders of pilot's ratings or certificates, in the reserve organizations of the United States Army, United States Navy or Marine Corps.
2. Holders of Federation Aëronautique Internationale Aviators' certificates issued prior to May 20, 1926.
3. The persons mentioned in subparagraph (A), who have not had the solo flying required by Section 65.

(C) *As Private Pilots.*—

1. Any of the classes of persons mentioned in subparagraph (A) and (B) who have had (1) at least five hours of solo flying within the year immediately preceding the filing of their applications, or (2) at least 50 hours of solo flying since the granting of their ratings or certificates.
2. Persons qualified as commercial pilots of any class who prefer to be licensed only as private pilots.

The exemptions mentioned in this section shall cease midnight, December 31, 1927, and will not be applicable to

persons whom the Secretary of Commerce finds have unsatisfactory piloting records.

Section 70—*Place, etc., of Examination*

Examinations for pilots' licenses will be held at such time and places as the Secretary of Commerce shall designate. Such examinations and tests will be conducted by an examining officer designated by the Secretary of Commerce. Candidates for pilots' licenses must furnish the airplanes in which the flight tests are to be made, unless the Secretary of Commerce makes other provisions therefor.

Section 71—*Duration and Renewal of Pilots' Licenses*

(A) Unless sooner revoked, transport and limited commercial pilots' licenses shall remain in force for six months and industrial and private pilots' licenses one year from date of issuance.

(B) Licenses will be renewed for like periods where the prescribed physical condition of the holder is shown by the same method as when the original license was issued, except that transport or limited commercial pilot must prove that he has had at least 10 hours of solo flying within the last sixty days, industrial pilots at least 25 hours within the last year, and private pilots at least 10 hours within the last year.

(C) If an applicant for renewal has not had the required solo flying and applies for a renewal within six months after the expiration of his last license, a new license will be issued to him upon proof of his physical qualifications and the passing of the flight tests required for the class of license he last held.

(D) Upon application to and permission of the Secretary of Commerce, the area for permissible flying of aircraft carrying passengers for hire or reward, designated in the licenses of limited commercial pilots, will be changed to other areas. Upon application and for good cause shown the licenses specified in this chapter may be extended for sixty days.

Section 72—*Mechanics' Qualifications and Examinations*

(A) An engine mechanic will be licensed upon passing an examination showing that he has sufficient knowledge of internal combustion engines, electricity, and power plant

of airplane types, and can properly inspect, repair, and overhaul airplane engines.

(B) An airplane mechanic will be licensed upon passing an examination showing that he is qualified in plane structure, rigging, and control and can properly inspect, repair and overhaul airplane structures.

(C) The examinations for both classes of licenses will be both theoretical and practical, and the candidate must attain an average of at least 70 per cent. A citizen of any country may be licensed if found qualified.

Section 73—*Duration and Renewal*

Mechanics' licenses, unless sooner suspended or revoked, will remain in force for two years after date of issue and will be renewed for additional two-year periods upon proof that during the term of the last license the holder has rendered services under his license during at least one-half of the term thereof. Upon application and good cause shown, the Secretary of Commerce may extend the license for a period of not more than sixty days.

Section 74—*Suspension or Revocation of Licenses*

Pilots' and mechanics' licenses will be suspended or revoked for—

(A) Violating any provision of the Air Commerce Act of 1926 or these regulations.

(B) Carelessness or inattention to duty.

(C) Unsound physical condition or any demonstration of incompetency in the operation or repair of aircraft.

(D) Being under the influence, or using, or having personal possession of intoxicating liquor, cocaine, or other habit-forming drugs while on duty.

(E) Refusal to exhibit license upon proper demand.

(F) Violating air traffic rules.

Section 75—*Personal Possession of Pilots' Licenses*

The pilot's license shall be kept in his personal possession when he is piloting an aircraft, and must be presented for inspection upon the demand of any passenger or any authorized official or employee of the Department of Commerce.

Section 76—*Pilots' Flight Records*

A licensed pilot must keep an accurate record of his flying time.

Section 77—*Meaning of Solo Flying*

As used in these regulations, a person is engaged in solo flying when he is the sole operator of the controls and is in command of the aircraft, in flight.

AIR TRAFFIC RULES

Section 78—*Law*

The Secretary of Commerce shall by regulation establish air traffic rules for the navigation, protection, and identification of aircraft, including rules as to safe altitudes of flight and rules for the prevention of collisions between vessels and aircraft. [Air Commerce Act, Sec. 3 (e)]

Section 79—*Unlawful Acts*

It shall be unlawful . . . to navigate any aircraft otherwise than in conformity with the air traffic rules. [Sec. 11 (a) (5)]

Section 80—*Penalty*

Any person who violates any provision of subdivision (a) of this section . . . shall be subject to a civil penalty of $500.00. [Sec. 11 (b)]

Section 81—*Application of the Law*

In order to protect and prevent undue burdens upon interstate and foreign air commerce the air traffic rules are to apply whether the aircraft is engaged in commerce or noncommercial, or in foreign, interstate, or intrastate navigation in the United States, and whether or not the aircraft is registered or is navigating in a civil airway. [Statement of managers accompanying conference report, Air Commerce Act of 1926]

Section 82—*Take-off Rules*

The take-off shall not be commenced until there is no risk of collision with landing aircraft and until preceding aircraft are clear of the field.

Section 83—*Flying Rules*

(A) *Right-side traffic.*—Aircraft flying in established civil airways, when it is safe and practicable, shall keep to the right side of such airways.

(B) *Giving-away order.*—Craft shall give way to each other in the following order:

1. Airplanes.
2. Airships.
3. Balloons, fixed or free.

An airship not under control is classed as a free balloon. Aircraft required to give way shall keep a safe distance, having regard to the circumstances of the case. Three hundred feet will be considered a minimum safe distance.

(C) *Giving-away duties.*—If the circumstances permit, the craft which is required to give way shall avoid crossing

ahead of the other. The other craft may maintain its course and speed, but no engine driven craft may pursue its course if it would come within 300 feet of another aircraft, 300 feet being the minimum distance within which aircraft, other than military aircraft of the United States engaged in military maneuvers and commercial aircraft engaged in local industrial operations, may come within proximity of each other in flight.

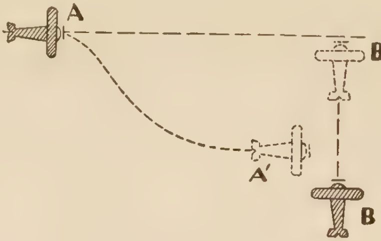

Fig. 176.—Crossing planes.

(D) *Crossing.*—When two engine driven aircraft are on crossing courses the aircraft which has the other on its right side shall keep out of the way. That is: "A," Fig. 176, must keep out of the way of "B." The nearest it may approach is 300 feet from "B." If there is sufficient space "A" may simply follow the course "A–A," which will bring him back of "B," who will by that time have reached "B."

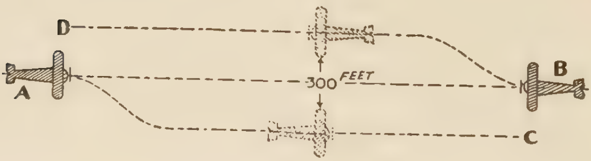

Fig 177.—Meeting planes.

(E) *Approaching.*—When two engine driven aircraft are approaching head-on, or approximately so, and there is risk of collision, each shall alter its course to the right, so that each may pass on the left side of the other, Fig. 177. This rule does not apply to cases where aircraft will, if

each keeps on its respective course, pass more than 300 feet from each other.

(F) *Overtaking.—*

1. *Definition:* An overtaking aircraft is one approaching another directly from behind or within 70° of that position, and no subsequent alteration of the bearing between the two shall make the overtaking aircraft a crossing aircraft within the meaning of these rules or relieve it of the duty of keeping clear of the overtaken aircraft until it is finally past and clear. That is: "B" in Fig. 178 is an

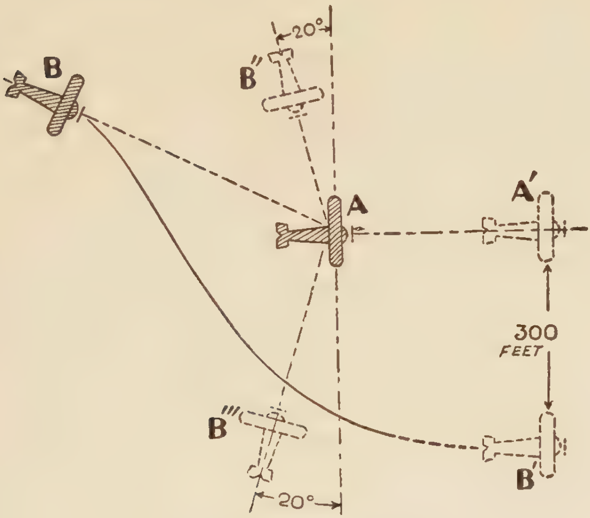

Fig. 178.—Passing and crossing planes.

overtaking aircraft, as it approaches "A" at an angle of less than 70°. It must keep clear and allow "A" to proceed on its present course. "B" is a crossing plane as the angle is more than 70°. It must also keep clear as it approaches from the left. "B" is likewise a crossing plane but it has the right of way as it comes from the right.

2. *Presumption:* In case of doubt as to whether it is forward or abaft such position it should assume that it is an overtaking aircraft and keep out of the way.
3. *Altering course:* The overtaking aircraft shall keep out

of the way of the overtaken aircraft by altering its own course to the right, and not in the vertical plane.

(G) *Height over congested and other areas.*—Exclusive of taking off and landing, and except as otherwise permitted by Section 88, aircraft shall not be flown:

1. Over the congested parts of cities, towns, or settlements except at a height sufficient to permit of a reasonably safe emergency landing, which in no case shall be less than 1,000 feet.
2. Elsewhere at height less than 500 feet, except where indispensable to an industrial flying operation.

(H) *Height over assembly of persons.*—No flight under 1,000 feet in height shall be made over any open-air assembly of persons, except with the consent of the Secretary of Commerce. Such consent will be granted only for limited operations.

(I) *Acrobatic flying.*—

1. Acrobatic flying means intentional maneuvers not necessary to air navigation.
2. No person shall acrobatically fly an aircraft—
   (a) Over a congested area of any city, town or settlement.
   (b) Without the approval of the Secretary of Commerce, over any open-air assembly of persons, or below 2,000 feet in height over any established civil airway, or at any height over any certified airport or landing field, or within 1,000 feet horizontally thereof.
3. No person shall acrobatically fly any airplane carrying passengers for hire or reward.

(J) *Dropping objects or things.*—Except when necessary to the personal safety of the pilot, passengers, or crew, when an aircraft is in flight the pilot shall not drop or release, or permit any person to drop or release, any object or thing which may endanger life or injure property.

(K) *Seaplanes on water.*—Seaplanes on the water shall maneuver according to the laws and regulations of the United States governing the navigation of water craft, except as otherwise provided herein.

Section 84—*Landing Rules*

(A) *Up wind.*—Landings shall be made into or up wind when practicable.

(B) *Course.*—If practicable, when within 1,000 feet horizontally of the leeward side of the landing field the airplane

shall maintain a direct course toward the landing zone.

(C) *Right over ground planes.*—A landing plane has the right of way over planes moving on the ground or taking off.

(D) *Giving way.*—When landing and maneuvering in preparation to land, the airplane at the greater height shall be responsible for avoiding the airplane at the lower height, and shall, as regards landing, observe the rules governing overtaking aircraft.

(E) *Distress landings.*—An aircraft in distress shall be given free way in attempting to land.

Section 85—*Lights*

(A) *Angular limits.*—The angular limits laid down in these rules shall be determined as when the aircraft is in normal flying position.

(B) *Airplane lights.*—Between one-half hour after sunset and one-half hour before sunrise airplanes in flight must show the following lights:

1. On the right side a green light and on the left side a red light, showing unbroken light between two vertical planes whose dihedral angle is 110° when measured to the right and left, respectively, from dead ahead and to be visible at least 2 miles.

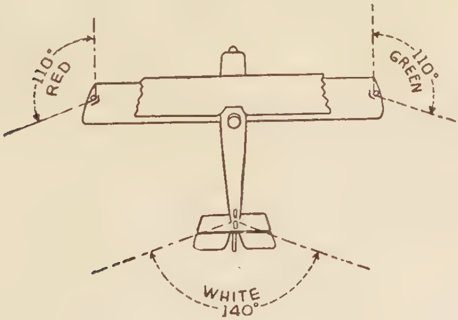

Fig. 179.—Area of lights.

2. At the rear and as far aft as possible a white light shining rearward, visible in a dihedral angle of 140° bisected by a vertical plane through the line of flight and visible at least three miles. Fig. 179.

(C) *Airship lights.*—Between one-half hour after sunset and

one-half hour before sunrise airships shall carry and display the same lights that are prescribed for airplanes, excepting the side lights shall be doubled horizontally in a fore-and-aft position, and the rear light shall be doubled vertically. Lights in a pair shall be at least seven feet apart.

(D) *Balloon lights.*—A free balloon, between one-half hour after sunset and one-half hour before sunrise, shall display one white light not less than 20 feet below the car, visible for at least two miles. A fixed balloon, or airship, shall carry three lights—red, white, and red—in a vertical line, one over the other, visible at least two miles. The top red light shall be not less than 20 feet below the car, and the lights shall be not less than seven nor more than ten feet apart.

(E) *Lights when sationary.*—

1. Between one-half hour after sunset and one-half hour before sunrise all aircraft which are on the surface of water and not under control, or which are moored or anchored in navigation lanes, shall show a white light visible for at least 2 miles in all directions.
2. Balloon and airship mooring cables between one-half hour after sunset and one-half hour before sunrise shall show groups of three red lights at intervals of at least every 100 feet measured from the basket, the first light in the first group to be approximately 20 feet from the lower red balloon light. The object to which the balloon is moored on the ground shall have a similar group of lights to mark its position.

Section 86—*Day Marks of Masts, etc.*

By day, balloon and airship mooring cables shall be marked with tubular streamers not less than eight inches in diameter and seven feet long and marked with alternate bands of white and red, twenty inches in width. The object to which the balloon or airship is moored on the ground shall have the same kind of streamers, which must be in the same position as the lights specified herein.

Section 87—*Signals*

(A) *Distress.*—The following signals, separately or together, shall, where practicable, be used in case of distress:

1. The international signal, S O S, by radio.
2. The international code flag signal of distress NC.

3. A square flag having either above or below it a ball, or anything resembling a ball.
4. A succession of white Very's pistol lights fired at short intervals.

(B) *Weather signals.*—At certified lighted airports and fields and at emergency fields operated by the Secretary of Commerce, one red fusee, or approved equivalent, is a warning of approach of unfavorable flying weather, and two red fusees, or approved equivalents, are a definite signal that the weather conditions make it imperative that aircraft should proceed no farther.

(C) *Signal when compelled to land.*—When an aircraft is forced to land at night at a lighted airport it shall signal its forced landing by firing a red Very's light or making a series of short flashes with its navigation lights if practicable to do so.

(D) *Fog signals.*—In fog, mist, or heavy weather an aircraft on the water in navigation lanes, when its engines are not running, shall signal its presence by a sound device emitting a signal for about five seconds in two-minute intervals.

Section 88—*Deviation From Air Traffic Rules*

The air traffic rules may be deviated from when special circumstances render a departure necessary to avoid immediate danger or when such departure is required because of stress of weather conditions or unavoidable cause.

Section 89—*Civil Penalties*

Any person who (1) violates any provision or subdivision (a) of this section or any entry or clearance regulation made under section 7, or (2) any customs or public health regulation made under such section, or (3) any immigration regulation made under such section, shall be subject to a civil penalty of $500.00, which may be remitted or mitigated by the Secretary of Commerce, the Secretary of the Treasury, or the Secretary of Labor, respectively, in accordance with such proceedings as the Secretary shall by regulation prescribe. . . . [Air Commerce Act, Sec. 11 (b)]

Section 90—*Penalty Proceedings*

The Secretary of Commerce will notify all persons of the incursion of penalties subject to mitigation or remission by him and any person charged with the same may transmit to the Secretary of Commerce two copies of an affidavit stating the facts upon which the penalty was incurred, with a request for mitigation or remis-

sion. The Secretary of Commerce will then determine whether or not the penalty will be remitted or mitigated, and the person making the request will be notified accordingly.

Section 91—*Waiver of Regulations*

The Secretary of Commerce may waive any of the requirements of these regulations when, in his discretion, the particular facts justify such waiver.

Section 92—*Savings Clause*

These regulations as amended shall take effect midnight, March 22, 1927. An aircraft required to be licensed under the Air Commerce Act of 1926 may operate under a letter of authority from the Secretary of Commerce pending the official examination of such aircraft, provided the application for aircraft license is on file with the Secretary of Commerce. Airmen required to be licensed under said act and who have filed their application for licenses will be permitted to perform duties as licensed airmen of the class for which they apply, pending their official examination by the Secretary of Commerce.

CHAPTER XXII

AËRONAUTICAL WORDS, TERMS AND DEFINITIONS

ACCELERATION.—Increase in velocity, or speed. When a body falls, under the influence of the earth's gravity, it is always found to possess a uniform acceleration of thirty-two feet per second.

ACROBATICS.—The handling of an airplane so that it assumes acute angles in the air other than those necessary for straight flying. Also called stunts. Looping, tail spinning, wing slipping, steep spirals or any like maneuver is called acrobatics.

AËRODYNAMICS.—The study of the action of air on moving surfaces.

AILERON.—A small movable airfoil, that controls lateral position.

AIRFOIL.—A complete surface structure whose function is to suspend or to alter the position of an airplane through air force.

AËRONAUTICS.—Pertaining to matters aërial, as mechanical flying.

AIR CHUTE.—A trade name for a certain make of parachute.

AIRMAN.—Primarily a pilot, but anyone physically connected with aviation, including pilot, mechanic, rigger, airport official, designer, manufacturer.

AIRWAY.—An established route, identified by beacons and other landmarks, provided with emergency landing fields in addition to service fields, connecting two or more important centers.

AMPHIBIAN.—An airplane designed and equipped to operate from either land or water.

ANGLE OF INCIDENCE.—The angle that the chord of an airfoil makes with the flying position datum line of an airplane.

ANGLE OF ATTACK.—The angle at which a wing surface meets the wind passing it.

ASPECT RATIO.—Relation of the length of the span to the length of the chord.

ATMOSPHERE.—A gas containing 77 per cent nitrogen and 23 per cent oxygen.

ATMOSPHERIC PRESSURE.—The normal pressure of the atmosphere on objects, which is 14.7 pounds at 60° F. at sea level.

AVIATOR.—One having direct duties to perform aboard an aërial vehicle (airplane, dirigible, balloon).

AVIATRIX.—A feminine aviator.

AVIGATION.—A term given to aërial navigation.

BALANCED SURFACE.—A control surface, part of which is placed ahead of the hinge in order to assist the movement of the larger area behind the hinge.

BANK.—To tip sideways or laterally.

BIPLANE.—An airplane having an upper and a lower wing.

BUMPS.—Ascending and descending air currents affecting stability of ship.

CHORD.—The distance, measured on a straight line, from the leading edge to the training edge of an airfoil.

CAMBER.—The curve from leading edge to trailing edge of an airfoil.

CABANNE STRUTS.—The struts supporting the center section above the fuselage.

CEILING. (or Roof).—The highest altitude attainable by a ship. Also the under surface of clouds or fog.

CENTER OF GRAVITY.—The spot on an airplane where, if a pointed support were placed, the machine would balance exactly.

CENTER OF PRESSURE.—A lateral line on the wings where the lifting force is centered while the ship is in flight.

CENTER SECTION.—A small separate section of wing placed between the main wing sections, and rigidly braced to the fuselage to which the main wing sections are attached.

CHASSIS.—The structure that supports the fuselage while the plane is at rest upon the ground; includes the wheels, axle and bracing struts. Also called Landing Gear.

COCKPIT.—The compartment of the fuselage in which are the controls and accommodations for the pilot.

CRATE.—A slang name for an airplane, applied either in derision or affection.

CRITICAL ANGLE.—The angle of attack at which the lift is greatest and beyond which the airplane would stall.

DECALAGE.—The difference in angle of incidence of airfoils attached to the same ship.

"DEP" CONTROL.—A slang expression for Deperdussin control—a control system in which a wheel is mounted on top of the stick to control the movement of the ailerons.

DIHEDRAL.—The angle which the wings make with a true horizontal line, when their tips are higher than the center section.

DIRIGIBLE.—An elongated framework, housing a lifting medium in the form of sectional balloons, propelled by engines and guidable.

DOPE.—A chemical preparation applied to fabric surfaces to preserve them against the elements and to shrink them taut.

DRAG.—Any resistance to the free forward movement of an airplane.

DRIFT.—The difference between the heading and the actual course being covered by an airplane in flight, caused by wind striking it from direction other than directly fore-and-aft.

DURALUMIN.—An aluminum alloy, 95.5 per cent aluminum, 3 per cent copper, .50 magnesium, 1 per cent manganese—one-third the weight of steel.

ENTERING EDGE.—That edge entering the air stream first.

ELEVATORS.—Airfoil control surfaces, placed horizontally, that cause the ship to climb or dive.

EMPENNAGE.—The tail surface group of airfoils including the rudder, elevators, vertical stabilizer and horizontal stabilizer.

FACTOR OF SAFETY.—The breaking strength of a body divided by the maximum strain it is usually called upon to bear.

FERRY.—To fly a ship from point to point not on a regular mission, as when delivering from factory to dealer or purchaser. Corresponds to "dead-heading" on a railroad.

FIN.—A slang name for the vertical stabilizer.

FITTINGS.—The connection medium through which airplane parts are attached to each other.

FLIPPERS.—A slang name for the elevators.

FLYING WIRES.—The wires through which the weight of the plane is supported while in flight.

FORCE.—That which acts on a body to change or tend to change that body's state of rest, or uniform motion in a straight line.

FUSELAGE.—The body of an airplane in which is housed the crew, passengers and load.

GAP.—The perpendicular distance between the chords of two wing panels.

GLIDER.—A form of aircraft similar to an airplane but without motive power, depending upon wind currents and gravity to keep it in flight.

GLIDING ANGLE.—The angle made by the horizontal path and the natural path taken by an airplane when gliding to earth with the power shut off.

GRAVITY.—The attraction that the earth has on all bodies.

GUN.—A slang name for the engine throttle.

GYROSCOPE.—A rapidly revolving weighted wheel which resists any attempt to disturb its plane of rotation.

HEDGE HOPPING.—Extremely low flying.

HOP.—Slang for flight.

HELICOPTER.—A form of aircraft designed to rise straight, or nearly straight up from the ground, and also to accomplish forward flight.

INCIDENCE.—See *Angle of Incidence.*

INTERFERENCE.—The crowding of the air stream in the gap of a biplane causing the surfaces to interfere with free passage of the air stream and resulting in less lift being exerted.

INTERPLANE STRUTS.—Struts placed between the upper and lower wings of a biplane.

JOYCE STICK.—The control lever of an airplane which alters the position of the ailerons and elevators. Named for the inventor of the control system.

JOY STICK.—Slang name for the Joyce Stick.

KEEL SURFACE.—Any flat surface, more particularly those of the fuselage, tending to guide the airplane in a true forward path.

LANDING GEAR.—See *Chassis.*

LANDING WIRES.—The wires through which the weight of the wings is supported while the ship is traveling at less than flying speed or at rest upon the ground.

LEADING EDGE.—See *Entering Edge.*

LIFT.—The result of air forces acting on wing sections, or other surfaces, tending to support an airplane in flight.

Longerons.—The longitudinal frame pieces of the fuselage, corresponding to the side members of an automobile frame.

Manometer.—An instrument used for measuring the air pressure or air suction under different conditions as when measuring lifting forces acting on airfoils.

Monoplane.—An airplane having one wing on either side of the fuselage as a supporting medium.

Nacelle.—Another name for the fuselage, also an enclosure for an outboard motor.

Negative Aileron.—An aileron that makes a negative angle with the wind in flight; raised above the trailing edge of a panel.

Ordinate.—The distance from the chord to the camber line of an airfoil; measured to upper camber line is called the upper ordinate; measured to the lower camber line is called the lower ordinate.

Overhang.—That amount one wing extends beyond the span of the other wing.

Parachute.—A device composed of silken fabric which opens into a large canopy and attached to a person, providing slow descent in case of aërial accident. Called the aërial life preserver.

Parasite Drag.—Drag with no resultant lift.

Parasol.—A type of airplane having the fuselage supported a short distance below a single upper wing.

Pilot Chute.—A small parachute that is released first from a parachute and which, after catching the air, drags the large main parachute from its pack.

Pitch (of Propeller).—The distance the propeller would advance through the air, in one complete revolution, provided the air were solid.

Positive Aileron.—Aileron making a positive angle with the wind in flight; lowered below the trailing edge of a panel.

Power Plant.—The engine providing the necessary power to revolve the propeller.

Propeller.—A properly shaped part driven by the engine which, acting upon the air, tends to propel the aircraft.

Prop.—A slang term for the propeller.

Pusher.—The type of airplane having the propeller mounted at the rear of the engine so as to push the airplane through the air.

QUADRAPLANE.—An airplane having four wings, one above the other.

RADIAL ENGINE.—A type of engine in which the cylinders radiate from the crankcase in the manner of wheel spokes from the hub. The cylinders of a radial engine are stationary and the crankshaft revolves.

RELATIVE WIND.—The air passing a body, regardless of whether the body is stationary and the air moving, or the air stationary and the body moving.

RIB.—Part of the framework of a wing, pieces extending longitudinally from leading edge to trailing edge.

RIGGING.—The bracing struts and wires of an airplane; also the act of adjusting the surfaces to proper relation with each other.

RIP CORD.—The cord to which is attached the locking pins fastening the parachute pack flaps closed.

ROOT.—The end of a wing section attached to the fuselage.

ROTARY ENGINE.—Has the appearance of a radial engine but the cylinders revolve about a stationary crankshaft.

RUDDER.—The vertical airfoil attached to the tail of an airplane whose movement governs the direction of flight.

RUDDER BAR.—A control lever placed on the floor of the cockpit and operated by the pilot's feet to alter the position of the rudder.

RUNNING GEAR.—See *Landing Gear*.

SAFETY WIRE.—A small wire passed through turnbuckles and other fastenings in such a way as to prevent their undoing.

SCAVENGING OIL PUMP.—A pump used on engines to remove oil once used from the crankcase and return it to the oil cooler or reservoir.

SEAPLANE.—An airplane designed to operate from the surface of water.

SHIP.—The airman's name for aircraft.

SLIP (of Propeller).—The pitch of a propeller minus the actual distance of forward travel in one revolution.

SLIP STREAM.—The wind stream thrown backward by a propeller.

SOLO.—To fly alone, or in control of an aircraft.

SPAN.—The distance from wing tip to wing tip.

SPAR.—The main structural member of an airplane wing, running

out from the fuselage, and to which is attached the other structural members called ribs.

SPINNER.—A streamline shaped cowl placed over the center portion of the propeller or hub to reduce wind resistance.

STABILITY.—The power of a body which causes it, when disturbed from its steady motion, to automatically develop forces that try to restore the body to its original steady motion. In an airplane this means the inherent ability to return to a level line of flight after having been disturbed from that state.

STABILIZER.—A surface so placed as to return the airplane to a straight line of flight after having been disturbed from a straight line of flight.

STAGGER.—The amount of advance of the leading edge of one wing beyond the other.

STALL.—The condition of an airplane when the drag exactly equals the lift and it has lost the speed necessary for control surfaces to respond or airfoils to suspend.

STALLING ANGLE.—The angle of attack at which the drag exactly equals the lift.

STICK.—The control stick, Joyce stick, and propeller are sometimes referred to as the "stick."

STREAMLINE.—A shape or form of design that sets up no turbulence, eddies or resultant vacuum in passing through air or liquid.

STRUT.—A rigid brace.

SUPERCHARGER.—A mechanical device combining a high speed suction and pressure fan used to increase the velocity with which the engine gas mixture leaves the carburetor and enters the combustion chamber.

SWEEPBACK.—Sweepback exists when the leading edge at the wing tip is back of the leading edge at the center section.

SWITCH OFF. (Gas On).—A signal expression used between pilot and mechanic when cranking an aircraft engine to designate certain operations desired.

TAKE-OFF.—The act of an aircraft leaving the ground.

TAIL SKID.—A structural member placed at the extreme rear and under the fuselage to prevent the fuselage from touching or dragging on the ground.

TAXI.—The movement of an airplane on the ground.

TIP.—The outermost point of a wing away from the root.

TORQUE.—The force exerted by an engine revolving in one direction to revolve its support in the opposite direction.

TRACTOR.—The type of airplane, or engine-propeller unit, in which the propeller is mounted at the forward end to pull the aircraft through the air.

TRAILING EDGE.—The rear, or back edge of any part. That which follows behind the leading edge.

TRIPLANE.—An airplane having three wing sections, one above the other.

TURNBUCKLE.—A device consisting of two male members, one with a right hand thread and the other with a left hand thread, which fit corresponding threads in a female member. Turning the female member in a certain direction draws the two male members toward each other, thus reducing the distance between the outer tips of the male members. Used to vary the length of cables or struts.

UNDERCARRIAGE.—See *Landing Gear.*

VELOCITY.—Speed or rate of motion.

WASH (of Propeller).—The disturbed air which exists for some distance behind and after the passage of a propeller.

WASH-IN.—Increased angle of incidence toward the wing tip.

WASH-OUT.—Decreased angle of incidence toward the wing tip.

WASH-OUT.—A slang expression designating the complete wrecking of an aircraft.

WIND TUNNEL.—A device used to create conditions similar to actual flight in which models, or complete airplane units, may be tested aërodynamically.

YAW.—To veer from a straight directional path.

ZOOM.—An angle of climb greater than that at which the plane would climb under normal conditions, the necessary force being derived from the momentum of the ship. A steep angle of climb of short duration.

INDEX